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Dredging in an Active Artillery Impact Area Eagle River Flats, Alaska

Michael R. Walsh, Edwin J. Chamberlain, Karen S. Henry, Donald E. Garfield and Ed Sorenson

September 1996

Abstract: Remediation of sediments in permanently ponded areas at Eagle River Flats, a salt marsh contaminated with white phosphorus (WP), may require dredging. Because the Flats were used as a firing range impact area for over 40 years by the U.S. military, there is much unexploded ordnance, which will require that any dredging equipment be remotely controlled. To treat the sediment pumped from dredged areas, a spoils retention basin was designed, constructed, and tested. This basin contains several innovations, including a natural peaty-silt liner and a geofabric barrier to inhibit reintroduction of WP into the environment, and is designed for the natural remediation of the WP. The dredging system was deployed in October of 1994, with sampling indicating that WP-contaminated areas were removed from the dredged area. An early snowfall curtailed operations shortly after initiation.

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Prepared for
U.S. ARMY ENVIRONMENTAL CENTER

PREFACE

This report was prepared by Michael R. Walsh, Mechanical Engineer, Engineering Resources Branch, Technical Resources Center, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; Edwin J. Chamberlain, Research Civil Engineer, Applied Research Division, Research and Engineering Directorate, CRREL; Karen S. Henry, Research Civil Engineer, Civil and Geotechnical Engineering Research Division, Research and Engineering Directorate, CRREL; Donald E. Garfield, Mechanical Engineer, Engineering Resources Branch, Technical Resources Center, CRREL; and Ed Sorenson, Civil Engineer, Hydraulics and Hydrology Section, Civil Works Branch, Engineering Division, U.S. Army Corps of Engineers, Alaska District.

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Technical review of the manuscript was provided by Leonard Zabilansky and Jeffrey Stark of CRREL. Susan Hunnewell assisted with the filter fabric work. Dennis Lambert and Troy Arnold helped with the dredging operation. Charles Collins is the Science Coordinator for the Eagle River Flats Program and assisted with data collection and surveying. Laurie Angell and Bill Smith, Fort Richardson Directorate of Public Works—Environmental, provided critical administrative and logistical support. Travis Barber, Mike Hamilton, John McKiernan, and George Boice and his co-workers are much appreciated for their construction, excavation, and technical support throughout this program.

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Dredging in an Active Artillery Impact Area
Eagle River Flats, Alaska

MICHAEL R. WALSH, EDWIN J. CHAMBERLAIN, KAREN S. HENRY,
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INTRODUCTION

Ongoing investigations into the waterfowl die-offs and the persistence of the causal agent, white phosphorus, in Eagle River Flats, an estuarine salt marsh and military impact area, indicate that any remediation strategy will have to include consideration of removal and controlled processing of contaminated sediments. Contaminated areas that are constantly flooded, such as the deeper ponded areas, do not allow natural drying of the soil and subsequent sublimation of the residual white phosphorus (WP) particles. Some of these permanently flooded areas are interconnected over large areas and would be impractical to address through pond draining. These areas, which are generally vegetated and heavily used by affected dabbling ducks and swans, have been found to be contaminated even after five years in which no WP rounds have been fired into the Flats. Although some areas of the Flats have shown evidence of natural remediation due to drying cycles, the ponded areas still pose a substantial risk to waterfowl.

The objective of this project is to investigate the feasibility of using a small, remote-controlled dredge to remove sediments from contaminated ponded areas and treating the spoils in an open retention basin. The treatment method will be natural drying via atmospheric exposure consequently resulting in the sublimation of the contaminant, white phosphorus. Spoils are to be monitored prior to deposition in the retention basin, and studies initiated to determine the fate of the contaminated sediments undergoing treatment in the basin.

Dredging was chosen as a method of remediation because of the positive displacement of the contaminated material and the ability to treat the material in a controlled environment. Using a small dredge, limited areas can be addressed and transport of the contaminated material (spoils) to a retention basin for treatment can be quickly and efficiently conducted. Environmental impact, although not negligible, can be minimized through a careful dredging strategy and specific design criteria.

This report describes the preparations for dredging carried out during the spring and summer of 1994, and the short dredging operations conducted in mid-October of that same year. A detailed description of the retention basin design and performance is included. This project was a joint effort between the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), the U.S. Army Corps of Engineers, Alaska District (COE-AK), and the Environmental Division of the U.S. Army, Alaska, Directorate of Public Works (DPW).

FEASIBILITY STUDY

Before dredging could be considered as a remediation strategy, a feasibility study needed to be conducted to ensure that dredging was a viable option. This was conducted by Walsh and Garfield. Dredging in Eagle River Flats is unique for one major reason: the potential presence of large quantities of unexploded ordnance (UXOs). Other factors that will affect dredging include the seasonal high tides, elevating the spoils to the holding pond on the explosive ordnance disposal (EOD) pad, the presence of vegetation and driftwood, the long pumping distances, and, of course, the white phosphorus. The feasibility study was conducted in two phases. The first was a review of available basic literature on dredging followed by a more specific literature search. The second phase involved contacting and visiting manufacturers of small dredges to brief them on the unique situation at Eagle River Flats (ERF) and to discuss the feasibility of the pilot project, as well as to solicit their ideas on how it could be done.

Due to the short amount of time available for

this study, both the initial research as well as the literature search were quite limited. The literature search topic was amphibious dredges, as this was the initial thrust of the study. Unfortunately, very little relevant information could be found on this subject. Concurrently, several basic texts and conference proceedings on dredging were reviewed. Also, all the current pertinent reports on the phosphorus contamination problem at the Flats were reviewed. With this background information, we investigated possible dredge manufacturer contacts through the Thomas Registers and personnel at CRREL who had worked with small dredges in the past. The objective was to determine whether a small dredge capable of the special requirements of operating in the Flats was available or could be easily modified from existing equipment.

A set of preliminary specifications was assembled and a list of prospective contacts was compiled and the companies contacted. A brief explanation of the situation and the preliminary specifications were sent to each contact. We requested information on their product lines and asked about visiting their facilities in the future to discuss the project in more detail and to get a better feel for their capabilities and strengths. A short list of five manufacturers was assembled and appointments to visit them were made. An information packet (Appendix A) was then assembled to be given to each manufacturer during the visit. Samples of the ERF sediments consisting of pond bottom and shore material were bottled for the manufacturers to give them a better feel of the material to be dredged. We then visited with each of the five manufacturers to discuss the feasibility of the pilot project.

All the manufacturers visited felt the job was feasible. Their major concern, of course, had to do with the UXOs. There were many questions that needed to be answered before any of the manufacturers would be able to design a complete system for the pilot project and estimate both price and productivity. These questions needed to be addressed to the extent possible in the dredge specifications if the Project Manager decided to pursue the dredging option. A write-up of the study, including methodology and conclusions, the information packet given to the manufacturers, unresolved questions, contacts, notes on the meetings, background information on each company, and impressions of the visits and the companies' capabilities by the two interviewers, was given to the Project Manager.

Our opinion from this feasibility study was that dredging is feasible at the Flats. To obtain reasonable production rates, the job will require a larger machine (20- to 25-cm pump) than originally estimated. Rather than design a machine specifically for the job, we felt we should try to use as standard a machine as practical to keep down costs and facilitate repairs and replacement parts. A modular design would be ideal. We moved more towards the use of a cable/capstan-propelled and guided floating dredge rather than an amphibious unit, as a floating unit would be more readily available, less expensive, easier to operate, and could be delivered sooner. Overall, if sufficient logistical and construction support from the Directorate of Public Works at Fort Richardson would be available and procurement of the equipment would not be delayed, conducting a demonstration project to confirm the feasibility of dredging as a form of remediation in the summer of 1994 would be achievable.

DREDGE SPECIFICATIONS

There were many factors to take into account when developing the specifications for the dredge to be used in the pilot study at the Flats. Among these were environmental impact, the presence of ordnance, personnel safety, and equipment transportability. No single dredge that we had seen was able to address all these factors as they relate to the Flats, so a specific set of criteria was drawn up for this application. In an attempt to minimize the cost of the system, the specifications were kept as close to standard as possible. However, some deviation from normal was necessary.

Environmental considerations

The first factor addressed was the dredge's impact on the environment. Eagle River Flats is an important migration route stopover, and as little permanent damage as possible should be done in the process of remediation. A small dredge will enable us to conduct the dredging process in a more controlled, limited manner. The dredgehead is specified as a shrouded, center-feeding auger that minimizes the dispersal of resuspended sediment, therefore reducing the risk of redeposition of WP particles on the surface of the pond bottom (Sherman 1984). The small size also makes it air-transportable by helicopter, thereby negating the need to channelize the Flats to move the dredge from one area to another. The strategy developed

for the overall remediation of contaminated ponded areas was to address small, one-hectare sites each year, reducing the impact of any one dredging season and allowing previously dredged sites to begin recuperating during operations in the out years. Finally, we had to plan for the worst: a detonation of a large caliber UXO by the dredge. Specifications were written such that a loss of a fixed volume of hydraulic fluid would trigger an automatic shutdown of the system. In addition, the fluid used is biodegradable and nontoxic, so spills should not adversely affect the environment. The dredge power supply, a diesel generator set, is located on shore to minimize problems caused by petroleum, oil, and lubricant (POL) spills.

Ordnance

The presence of UXOs is the other major design consideration. Using a defect rate of 5%, an estimated 10,000 unexploded rounds may be present in the Flats in various degrees of decay and sensitivity. There is no safe way of getting even a rough estimate on distribution and densities of these UXOs. Therefore, the dredge was specified to minimize the structural and financial impact of the detonation of a round during operations. The dredge was specified as modular in design to facilitate repair and replacement of damaged or destroyed components. High value assemblies, such as the pump and power system, are required to be far away from the dredgehead to reduce damage due to detonation. Spare parts and a complete spare unit were specified to reduce downtime in case of a catastrophic explosion.

As mentioned previously, the power system was designed to minimize the effects of a UXO detonation while dredging. The hydraulic system uses a nontoxic, biodegradable fluid (Mobil EAL 224H). System fluid loss will be limited due to a pump shutdown circuit that senses the hydraulic reservoir level. To eliminate the possibility of contaminating the Flats with diesel fuel, the power source for the dredge is located on shore and power is supplied via electric cable.

Safety

The issue of ordnance brought up another important design consideration: safety. The system was specified to be remotely controlled from an armored control cab. This cab, composed primarily of 13-mm-thick welded steel and 31-mm-thick ballistic polycarbonate (Lexan) windows, was blast tested in two separate tests using 105-mm high-explosive (HE) rounds at a distance of about 37 m. The structure sustained only minor damage due to shell fragmentation during the tests (Walsh and L'Heureux 1995). In the test where damage occurred, the round was placed on a wooden crate approximately 0.6 m above water level, with the back of the round pointed directly at the cab. This was considered a worst-case scenario by Captain Paul Arcangeli of the 176th EOD Detachment at Fort Richardson, who supervised testing.

Minimum distance to the dredge during active operations is 40 m. Therefore, to allow the operator to observe the dredging operation, a remote high-resolution wireless CCD video system is to be incorporated. Transmitted along with the video signal are the output of vital operating sensors, such as the various process pressures. This will allow the dredge operator to conduct operations as if he were onboard the vessel.

Separate from the dredge, a Health and Safety Plan (HASP) was required by the Fort Richardson Safety Office due to the hazards involved in the dredging operation. This document includes several pages of material specific to the dredging operation. Before the commencement of active dredging activities, the HASP was approved by a representative of DPW and the chief of the Fort Richardson Safety Office.

Transportability

Transport of the dredge is a critical design factor. To avoid adverse environmental impact resulting from channeling the Flats in the process of moving the dredge between contaminated areas, the unit needs to be air transportable. The options for transport by helicopter are the UH-1 (Huey), the UH-60 Blackhawk, and the CH-47 Chinook. Load capacity and operating cost per hour increase with each model, while availability decreases. The load capacity of the Huey, at 680 kg, is too low for practical consideration. The Blackhawk had a capacity of 3600 kg (upgraded to 4100 kg) and the Chinook has a capacity of 5400 kg. Therefore, the specifications were written such that the dredge should not weigh over 3600 kg unless a waiver is granted by the Program Manager. In that case, maximum weight is to be 5400 kg. Other features were specified to assist in movement and handling of the dredge.

Due to procurement difficulties, purchasing the dredge equipment was not possible in the time frame available, so a lease contract for the equipment was pursued. The contracting office of the U.S. Army, Alaska (USARAK) was tasked with the responsibilities of writing, bidding and awarding

a contract for equipment lease, support and maintenance for a dredging system for the Flats. A formal set of technical specifications was written up by CRREL and used by USARAK's Contracting Office in its request for bids.

Using the specifications as guidelines, CRREL engineers reviewed the technical portion of the bids received by the Contracting Office. These reviews were used in the overall evaluation of the bids and the contract was awarded to the entity deemed most appropriate by the Contracting Office: ChemTrack Services Group of Anchorage, Alaska. The dredges to be used are from Liquid Waste Technology, Inc., of Somerset, Wisconsin.

BASIN INVESTIGATIONS

Two of the most difficult issues to resolve during the pilot project were where and how the spoils are to be contained during treatment. The most obvious choice for a basin site is the EOD pad, a 6.3-ha gravel pad used until 1990 for the burning and detonation of dated, faulty or excess ordnance. The original plan was to clear vegetation from the pad and use as much of the pad as practical. A low berm would be constructed and the spoils from the dredging operation allowed to drain through the pad. However, the presence of contaminants in the EOD pad has resulted in the area being declared a Resource Conservation and Recovery Act (RCRA) site, thus requiring more thorough investigations into the use of the pad as a treatment site. Although this is an uncapped site, the Remedial Project Managers (RPMs) involved with the project felt that water filtering through the pad from spoils drainage was not acceptable and should be minimized.

Permission was granted for construction of a small, 0.8-ha retention basin with a controlled decanting structure at one end, contingent upon results of field and laboratory tests of the basin and pad characteristics. The Alaska District of the U.S. Army Corps of Engineers was tasked with design of the structure based on testing performed by CRREL. They were also responsible for overseeing the construction of the structure. Actual construction was carried out by the Roads and Grounds Office of the Directorate of Public Works (DPW) at Fort Richardson. CRREL engineers conducted the investigations into the basin and pad surface hydrology and acted as technical consultants throughout the effort.

Settlement times

Initial design studies focused on settlement times for the spoils. The treatment strategy was to pump the material into a retention basin, allow the solids to settle, and decant the supernatant over a weir, a strategy similar to that advocated by Poindexter (1984) and Palermo (1984). The drained sediments would then be allowed to dry naturally, and, climatological conditions permitting, the WP would sublimate. Settlement times are important in determining the dredge cycle as well as how much water will percolate through the bottom of the basin.

The objective of the settlement studies was to determine settlement rates and times for a one-day dredge cycle: 8–10 hours of dredging at 380 m^3/hour. The sediment cutoff size was ø 0.1 mm, the minimum WP particle size thought to be problematic in the waterfowl die-offs (Walsh 1994). Initial models using sediment particle sizes from previous analyses (Lawson and Brockett 1993) in freshwater indicated that settlement times for a 3/4-ha site would be on the order of days (Table 1). This model was based on Stoke's Law:

$$v = g(\rho_1 - \rho)d^2/18\mu \qquad (1)$$

Table 1. Settling times for spoils in fresh water.

Retention pond size (ha)	*Particle size (cm)*	*Settling velocity:silt (cm/s)*	*Settling velocity:WP (cm/s)*	*Pond depth (cm)*	*Silt settling time (hr)*	*WP settling time (hr)*	*Dredge cycle (days)**
0.75	0.01	7.0E-1	3.6E-1	40.53	0.02	0.03	0.3
0.75	0.001	7.0E-3	3.6E-3	40.53	1.61	3.14	0.5
0.75	0.0003†	6.3E-4	3.2E-4	40.53	17.89	34.88	1.8

*8-hour dredging plus retention time. No decanting time included.
†Median particle size (Lawson and Brockett).

where

v = particle settling velocity (cm/s: freshwater)
g = gravitational constant (980 cm/s^2)
ρ_1 = particle density (g/cm^3)
ρ = fluid density (g/cm^3)
d = particle diameter (cm)
μ = fluid viscosity ($dyne\text{-}s/cm^2$).

The Reynolds Number

$$R = v\rho d/\mu \text{ (dimensionless)} \tag{2}$$

is used to determine if settling is laminar or turbulent.

Settling times in Table 1 are given for both white phosphorus and silt particles. Times are a function of particle size and depth of ponded water. Note that the cycle time does not take into consideration the decanting time for removing the supernatant after settling is complete.

Laboratory sediment tests

The relatively long settlement times in Table 1 would adversely affect the dredging and filling operations. Several days of calm water in the settling basin would be required before relatively clear supernatant could form and be decanted over a weir. However, data indicate that the water in the Flats area is brackish. Tidal invasion of the Flats regularly introduces seawater, which mixes with freshwater from the Eagle River and groundwater sources. Salinity measurements in the region where the dredging is proposed indicated the salinity of the water was between 5 and 7 ppt (normal seawater has a salinity of about 36 ppt). Because settlement rates can be much higher in water that contains salts in solution (Thackson et al. 1984, Palermo et al. 1978) than in freshwater, settlements times on the order of hours rather than days were postulated after we recognized the impact of salts in the sediment–water solution. The electrolytes in saline sediments reduce the repulsive forces between soil particles. If the concentration of electrolytes is strong enough, particle repulsive forces will be neutralized. Particle attraction forces will then dominate and particle aggregation will become more common. The larger aggregations of particles will settle more quickly than the smaller individual particles. Only small salinity levels in the range of 2–6 ppt are required for the flocculation process to be effective (Praudic 1970).

Preliminary laboratory sedimentation tests with samples from ERF (Fig. 1) showed that settling times would be less than one hour, not the several

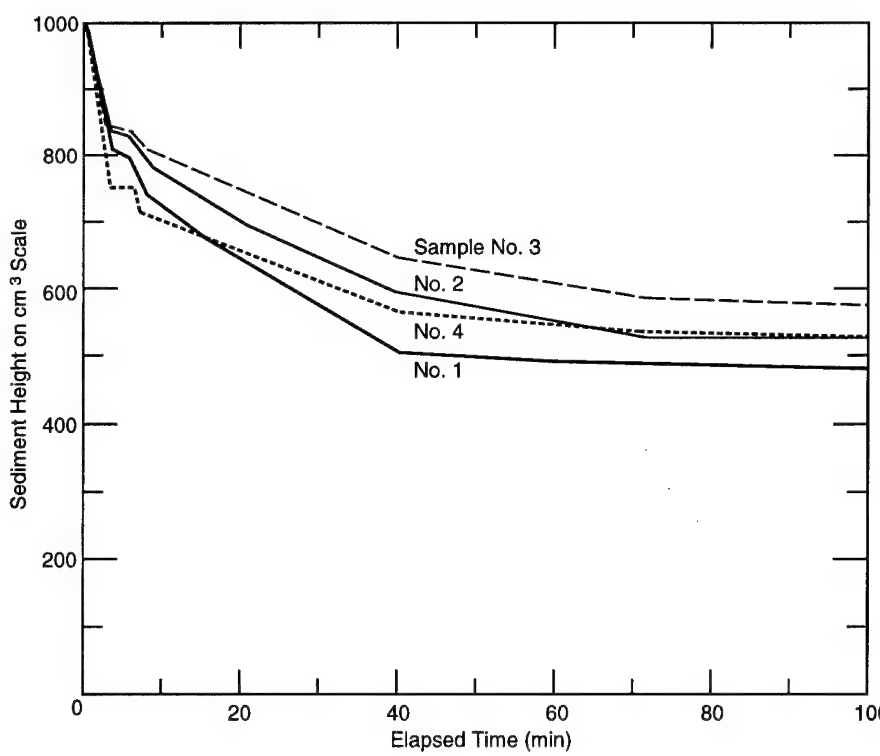


Figure 1. Results of preliminary sedimentation tests.

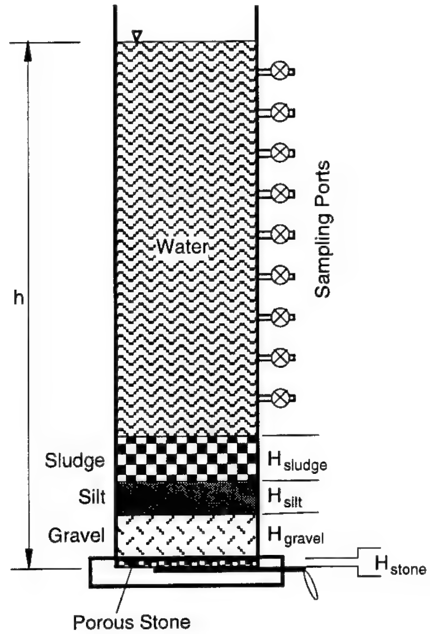


Figure 2. Montgomery tube used for sedimentation tests.

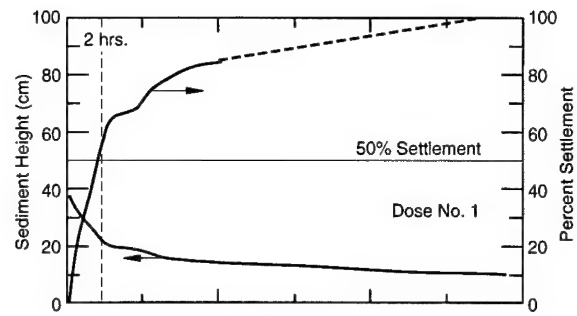
Table 2. Laboratory sedimentation test results following the Montgomery (1978) procedures.

Dose #1			*Dose #1R*			*Dose #2*			*Dose #3*		
Elapsed time (min)	*Interface height (cm)*	*Percent settled (%)*	*Elapsed time (min)*	*Interface height (cm)*	*Percent settled (%)*	*Elapsed time (min)*	*Interface height (cm)*	*Percent settled (%)*	*Elapsed time (min)*	*Interface height (cm)*	*Percent settled (%)*
0	38.0	0.0	1	51.0	0.0	0	68.3	0.0	0	74.7	0.0
2	37.5	1.8	2	51.0	0.0	1	68.0	0.9	2	74.5	0.9
3	37.3	2.7	3	50.9	0.4	3	67.7	1.7	5	74.4	1.3
5	37.0	3.6	5	50.8	0.9	5	67.3	2.8	10	73.8	4.0
7	36.8	4.5	6	50.5	1.8	7	66.8	4.3	15	73.1	7.1
10	36.0	7.2	10	50.0	3.6	10	66.2	6.0	20	72.5	9.8
20	34.0	14.5	15	49.5	5.4	15	65.3	8.5	30	71.1	16.0
30	32.5	19.9	20	48.8	7.9	20	64.5	10.8	45	69.6	22.7
48	30.0	29.0	30	47.7	11.9	30	63.0	15.1	60	68.3	28.4
60	28.5	34.4	45	45.8	18.8	45	61.2	20.2	75	66.9	34.7
77	26.8	40.8	60	44.4	23.8	62	59.5	25.0	90	65.5	40.9
90	25.3	46.2	78	42.7	30.0	75	58.4	28.1	110	63.8	48.4
105	23.8	51.6	90	41.5	34.3	90	56.9	32.4	120	62.9	52.4
120	22.0	58.0	105	40.0	39.7	105	55.5	36.4	132	61.9	56.9
135	20.8	62.5	120	38.4	45.5	120	54.1	40.3	172	58.3	73.1
150	20.3	64.3	135	36.8	51.3	132	53.1	43.2	180	57.5	76.4
165	20.0	65.2	150	35.0	57.8	180	48.3	56.8	195	55.0	87.6
180	19.8	66.1	165	33.8	62.1	195	46.9	60.8	221	53.3	95.1
205	19.5	67.0	180	33.4	63.5	210	45.0	66.2	240	52.8	97.3
240	19.0	68.8	221	32.6	66.4	240	43.0	71.9	270	52.2	100.0
243	18.6	70.3	240	32.3	67.5	245	42.8	72.4			
246	18.4	71.0	245	32.0	68.6	250	42.6	73.0			
255	18.1	72.1	251	31.6	70.0	255	42.5	73.3			
270	17.7	73.6	255	31.5	70.4	260	42.3	73.9			
285	17.3	75.0	260	31.4	70.8	270	42.1	74.4			
300	17.0	76.1	270	31.1	71.8	285	41.8	75.3			
330	16.3	78.6	285	30.7	73.3	295	41.6	75.9			
360	15.8	80.4	300	30.3	74.7	1380	33.1	100.0			
390	15.5	81.5	315	30.0	75.8	1410	33.1	100.0			
420	15.0	83.3	330	29.7	76.9						
1380	10.4	100.0	360	29.1	79.1						
1440	10.4	100.0	390	28.5	81.2						
			405	28.3	81.9						
			1380	23.3	100.0						

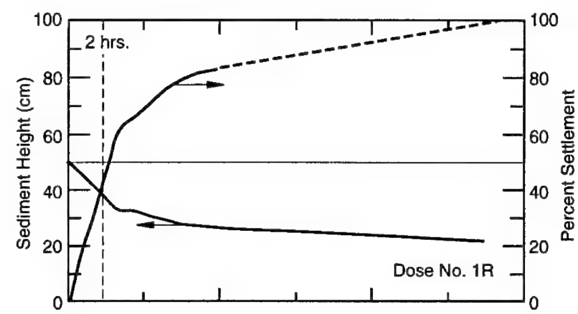
days required for freshwater sediments. More rigorous laboratory settlement tests following the method of Montgomery (1978) confirmed the preliminary tests. These sedimentation tests were conducted in a 15-cm-diameter polycarbonate tube with a length of about 1.8 m. The tube had a porous stone and drainage port in its base (see Fig. 2). Water was prepared at a salinity of 5 ppt and mixed with sediment at a ratio of four parts water to one part wet sediment by volume (70% water content by weight). The water content for the sediment was obtained from an estimate of the water content in the sediments that the dredge would pump into the settling pond. The sediment was thoroughly mixed to its initial water content in a laboratory blender (in contrast to hand mixing in the preliminary tests) and then mixed in a barrel with the saline water using a stirring agitator. It was then quickly poured into the sediment tube. The elevation of the interface at the top of the sediments was then monitored for at least 24 hours. A definite interface formed within a few minutes, the water above the interface being relatively transparent. Table 2 and Figure 3 show the test results. In all cases, 50% of the total settlement occurred in about two hours. In the preliminary tests, 50% of the total settlement occurred in about 15 minutes. The difference between these results is probably related to the size of the soil aggregates used in the two tests and the quality of the mixing. The aggregates were much coarser in the hand-mixed test than the machine-mixed tests, thus settling more quickly. The two cases probably bracket the range of results that would be achieved in the dredging operation.

These tests confirmed our preliminary study and gave us confidence that we could readily conduct the dredging, filling and decanting operations in daily cycles. However, we had to be assured that any white phosphorus in suspension would drop from suspension in the two-hour window of time. We conducted a fourth sedimentation test, this time with white phosphorus particles in suspension. We spiked the sediment with white phosphorus particles obtained from the Flats by Marianne Walsh of CRREL. White phosphorus particles of the size considered to affect the health of the waterfowl were used (≈ ø 0.1 mm [Walsh personal communication*]). Water samples were taken through ports located at 15-cm intervals in

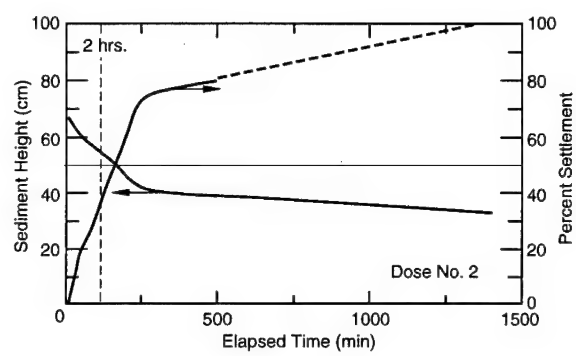
*M.E. Walsh, Applied Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.



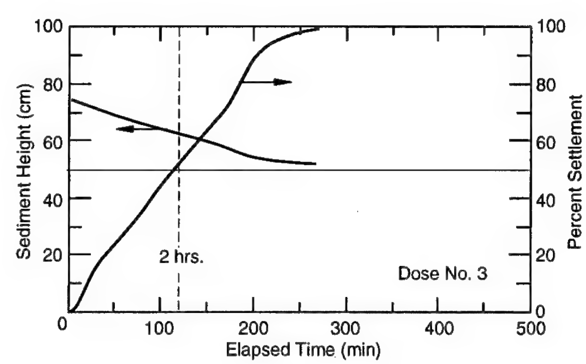
a. Dose #1.



b. Dose #1R.



c. Dose #2.



d. Dose #3.

Figure 3. Sedimentation test results in Montgomery tube.

Table 3. Results of GC analysis for WP in water column above simulated dredge spoils.

Hour	*Label*	*Peak ht.*	*WP mass (µg)**	*Calibration*
1	S-1	185	0.0082	Standard (70 µg/L)
1	S-2	175	0.0077	Peak Ht.
1	S-3	200	0.0088	4994
1	S-4	263	0.0116	4433
1	S-5	180	0.0080	5201
1	S-6	0	ND†	4893
2	S-1	0	ND	4799
2	S-2	0	ND	4694
2	S-3	0	ND	4188
2	S-4	0	ND	4765
2	S-5	0	ND	Average = 4745.875
2	S-6	0	ND	RF [peak ht/mg/L)] = 67.8
4	F-1	0	ND	
4	F-2	0	ND	
4	F-3	0	ND	
4	S-1	0	ND	
4	S-2	0	ND	
4	S-3	0	ND	
4	S-4	0	ND	
4	S-5	0	ND	
4	S-6	0	ND	

*34-mL aliquot of water extracted with 3.0 mL isooctane.
†Not detected; detection limit 0.006 µg.

the side of the sedimentation tube starting after one hour of settling. The results, shown in Table 3, indicate that no WP particles were found in suspension. All of the WP particles placed in suspension appeared to have settled in one hour or less. Concentrations are indicative of dissolved WP.

Weir flow

After the sediment has settled sufficiently to ensure that WP particles in the target range are no longer suspended in the water column (≈ two hours), the supernatant must be decanted. To do this, a drop inlet structure in the corner of the retention basin opposite the spoils inlet was designed. Decantation of the supernatant from the basin is to be done over an adjustable weir (Fig. 4).

The weir was modeled to ensure that the de-

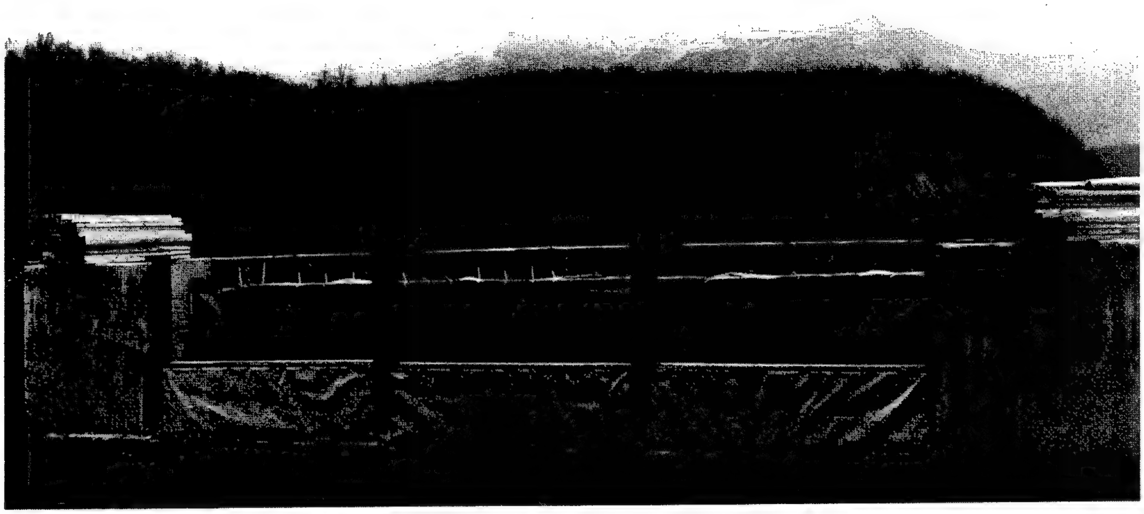


Figure 4. Drop inlet structure, showing adjustable weir.

sign would be sufficient to allow drainage of a day's dredging supernatant in a reasonable amount of time, six to eight hours, without velocities that would resuspend the poorly consolidated settled solids or damage the filtering fabric located 2 m behind the weir.

The following analysis of the drainage of the Spoils Retention Basin, sited on the EOD at Eagle River Flats, Alaska, uses the Francis Formula for fluid flow over a rectangular, sharp-edged weir. In a normal eight-hour dredge cycle, approximately 2400 m^3 of water will be pumped into the retention basin, assuming a 380-m^3/hour production rate and a 4:1 ratio of water to spoils (by volume).

The initial analysis is of flow rates over a 3.2-m weir for a given head. The height of the weir is given as about 15 cm. Although the weir height affects the flow rate, it will not be considered here, as the effect is minimal for low heads (< 0.3 m). We will be operating with heads of 0.1 m or less. The reason for this is to minimize the turbulence in the sheet flow towards the weir. Boundary conditions and the instantaneous flow rate equation are given below:

H = 0.1, 0.098 ... 0.01 (Head, or height of water above weir in meters)

P = 0.15, L = 3.2 (Height and length of weir in meters)

g = 9.81 (gravitational constant, m/s^2)

$$Q(H) = 2.54\,[L - 0.2(H)]\,(H)^{1.5}\,(3600) \text{ (Flow rate, } m^3\text{/hour [Hicks 1972]).} \quad (3)$$

Figure 5 is a graph of the instantaneous flow rate over a 3.2-m (10 ft) weir. The volume retained in the 0.8-ha retention basin above the weir can be expressed as

$$V(H) = AH = 2\,(4047)\,H\ (m^3). \quad (4)$$

One of the primary concerns in the retention pond design is the flow over the weir, which will be impacting the silt fence located between the weir and the basin outflow culvert. To get a handle on this, we can analyze the effect of differing weir length for a given head on the flow rate, in cubic yards per hour. This is an extension of

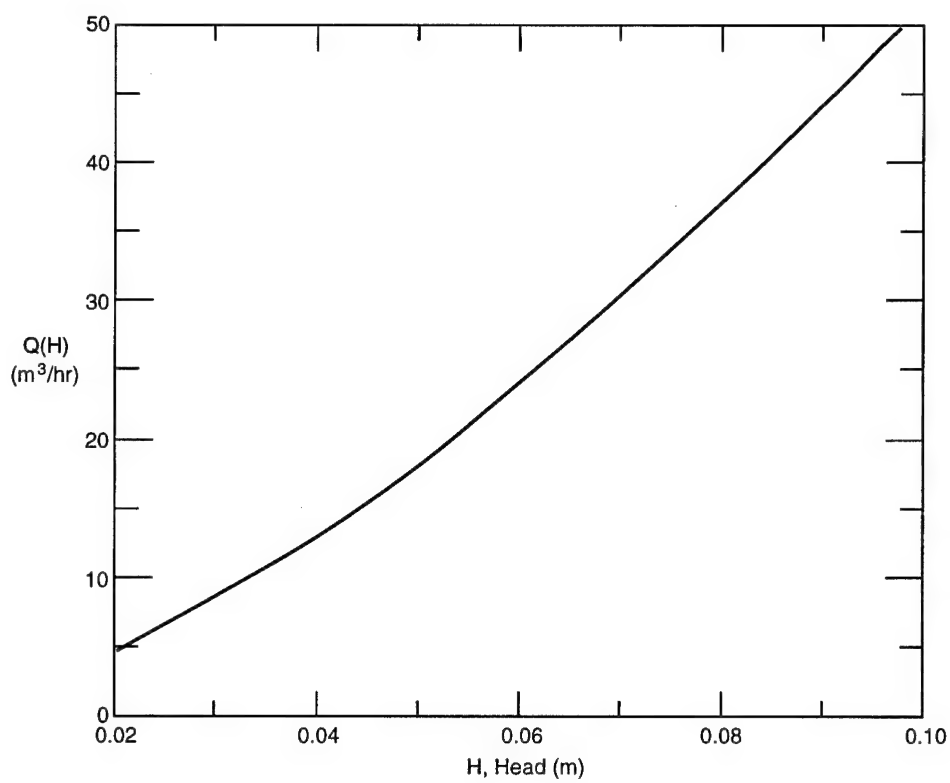


Figure 5. Instantaneous flow over a rectangular weir.

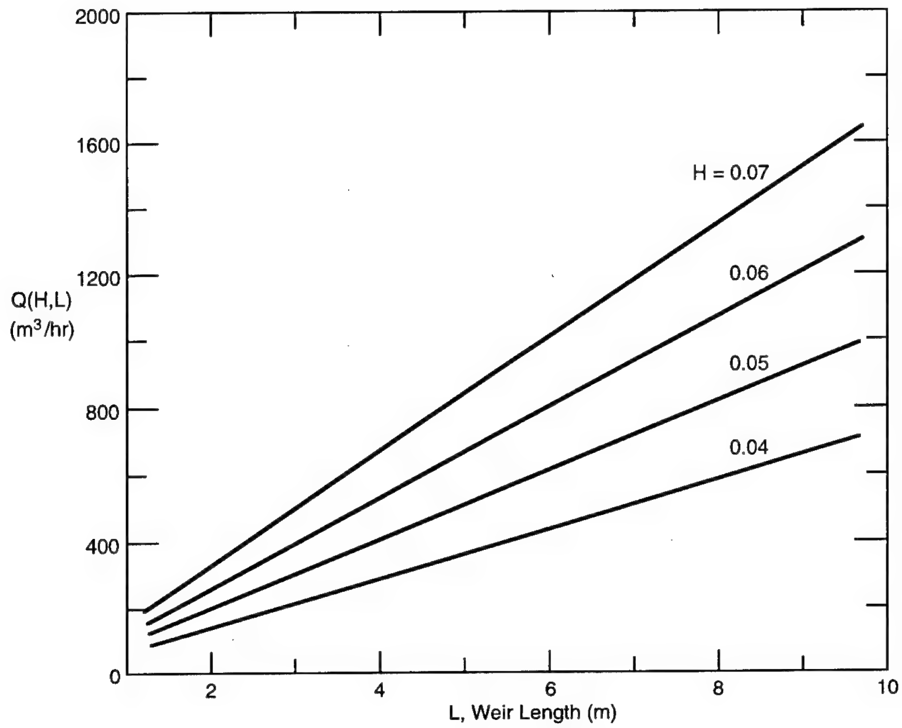


Figure 6. Instantaneous weir flow rates for various heads.

the previous calculations:

$H = 0.04, 0.05 \ldots 0.07$ (m)
$P = 0.15$ (m), $g = 9.81$ (m/s^2)
$L = 1.2, 1.3 \ldots 9.7$ (m)

$$Q(H) = (9144)\,[L - 0.2(H)]\,(H)^{1.5}\ (\text{m}^3/\text{hour}). \quad (3a)$$

The instantaneous effect of head on flow rates over the weir is illustrated in Figure 6. This, of course, is a linear relationship. We can now look at the time-required-to-drain relationship for a given weir length. The following relationships are used:

$L = 3.05$ (m)

$$Q(H) = 9144\,[L - 0.2(H)]\,(H)^{1.5}\ (\text{m}^3/\text{hour}) \quad (3a)$$

$$V(H) = (8094)\,H\ (\text{m}^3). \quad (4a)$$

An integral was developed to derive the time required to drain based on the flow *(Q)*: volume *(V)* relationship. It is integrated over the change in head over the fixed weir:

$$t = \int_{H_2}^{H_1} \frac{1}{H}\left(\frac{V(H)}{Q(H)}\right) dH\ (\text{hour}). \quad (5)$$

Now we can look at drainage times (in hours) as a function of weir length:

$L = 2.44, 3.94, \ldots 9.5$ (m)

$$Q(H) = (9144)\,[L - 0.2(H)]\,(H)^{1.5}\ (\text{m}^3/\text{hour}) \quad (3a)$$

$$V(H) = (8094)\,H\ (\text{m}^3) \quad (4a)$$

$$t = \int_{0.005}^{0.076} \frac{1}{H}\left(\frac{V(H)}{Q(H)}\right) dH\ (\text{hours}). \quad (5a)$$

Evaluating this integral yields the graph in Figure 7.

To confirm this analysis, we can look at Hicks' analysis of the variation in head on a weir without inflow to the reservoir, essentially what we have here. The formula used in Hicks (1972) is

$$t = [2A/CL]\,(1/h_2^{0.5} - 1/h_1^{0.5})\ (\text{hours}) \quad (6)$$

where
t = drainage time (hours)
A = pond area (m^2)
C = 1.83, the discharge coefficient
L = weir length (m)

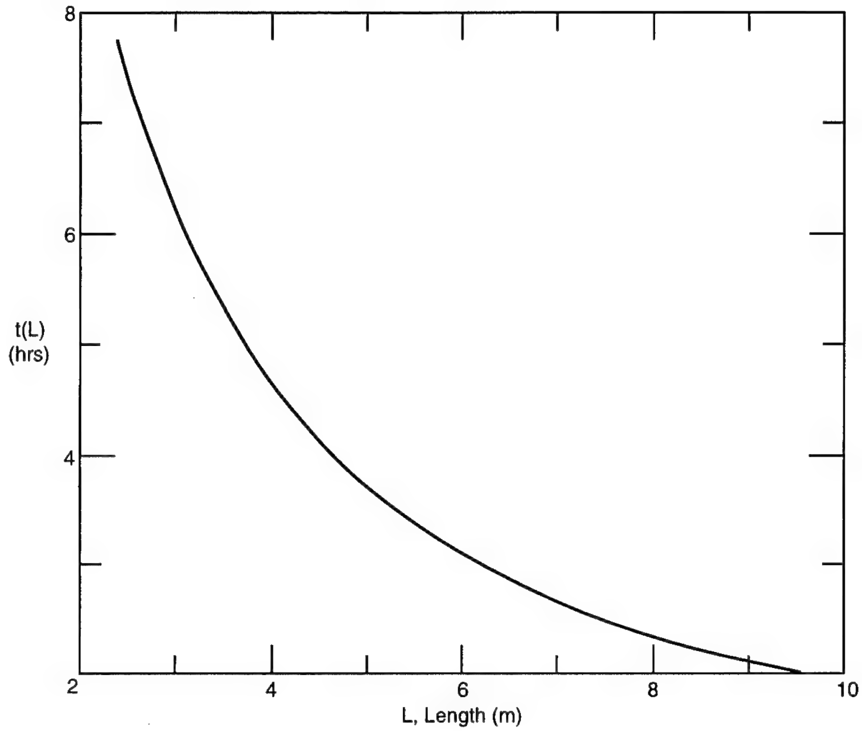


Figure 7. Basin drainage times as a function of weir length.

h_1, h_2 = starting and ending heights of water over the weir.

For the retention basin design, the following relationships will be used:

$$t = [2A/CL]\,(1/h_2^{0.5} - 1/h_1^{0.5}) \text{ (hours)}$$
$$A = 8094 \text{ m}^2$$
$$C = 1.83$$
$$L = 2.44, 3.94, \ldots 9.75$$
$$h_1 = 0.076,\ h_2 = 0.005 \text{ (m).} \tag{6}$$

Iteration of the above yields a curve (Fig. 8) very similar to that from the above integration.

A weir of 3.6 m or more will be necessary to ensure timely drainage of the retention pond. This can be accomplished with two to four 4.9-m (8 ft) weirs. A more detailed look at drainage times for weirs between 4.5 m and 7.5 m is shown on the next page (Fig. 9).

The curve was derived using the following relationships:

$$L = 4.88, 5.18, \ldots 7.32 \text{ (m)}$$

$$Q(H) = 9144\,[L - 0.2(H)]\,(H)^{1.5} \text{ (m}^3\text{/hour)} \tag{3a}$$

$$V(H) = (8094)\,H \text{ (m}^3\text{)} \tag{4a}$$

$$t = \int_{0.005}^{0.076} \frac{1}{H}\left(\frac{V(H)}{Q(H)}\right) dH \text{ (hours).} \tag{5a}$$

A 6-m (20 ft) weir looked to be the most effective for the retention basin application, with drainage times between 4 and 4.5 hours. Note that draining is to 0.5 cm (0.2 in.) above the weir. Draining to 0.25 cm (0.1 in.) above the weir increases total draining times by 50%. Note also that in this analysis, an assumption is made that all of the suspended solids have settled out of solution. This is definitely not going to be the case. Therefore, these calculations should be quite conservative. The above model indicates that the best procedure for decanting may involve graduated draining of the supernatant. If 0.3 m of water needs to be decanted, it should be drained in three or four steps.

The weir used is rectangular and adjustable, with adjustment made by removing 4-cm- (1 5/8 in.) thick boards. Two boards are to be removed at a time from each of the three weir sections to ensure low flow turbulence in the pond.

Supernatant filtering

Settlement calculations were based on 0.1-mm-dia. WP particles, as stated above. These criteria were chosen because this particle size was sieved from sediments by dabbling ducks. However, data

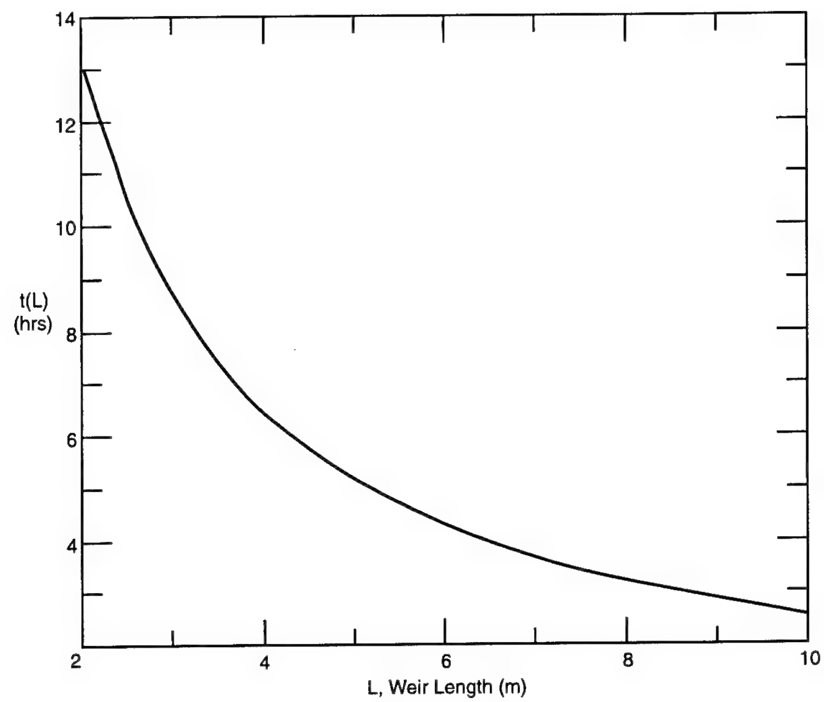


Figure 8. Confirmation of integral relationship.

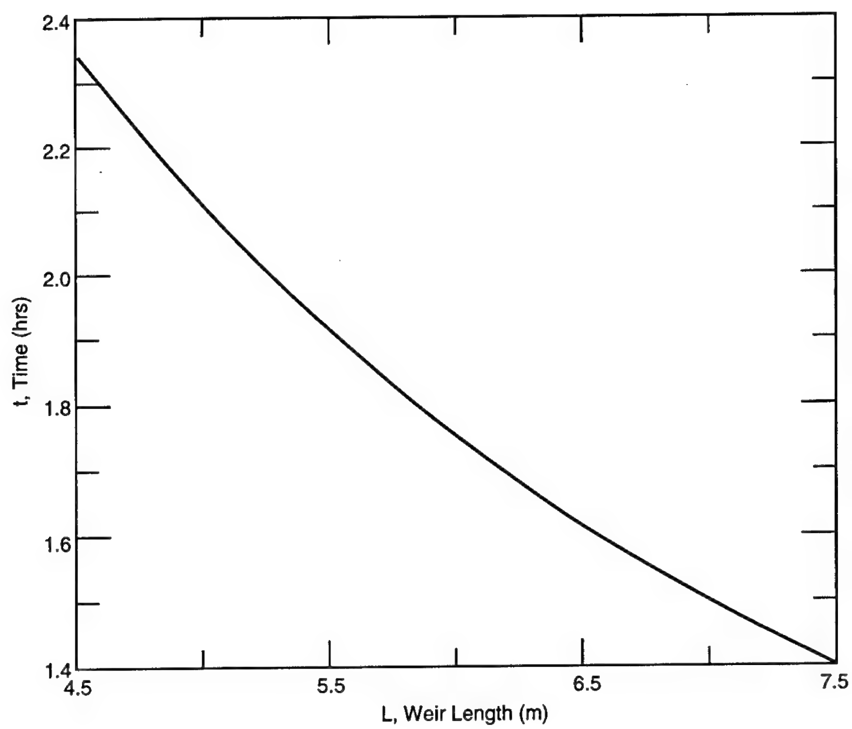


Figure 9. Drainage times for 4.5- to 7.5-m weirs.

indicate that the sediment size ranges down to 0.001 mm and less, with 50% coarser than 0.003 mm (by weight) (Lawson and Brockett 1993). Settling out these fines in a reasonable time frame in the area allotted is not possible, so a large number of very fine particles may be decanted off along with the supernatant. Along with these particles, particles of larger size may become resuspended during the decanting process. Concern over recontamination of the Flats by these larger particles was expressed, so filtering investigations using sediments from the Flats were conducted at CRREL (Henry and Hunnewell 1995, Henry et al. 1996). After extensive testing using a modeling flume built at CRREL, a candidate fabric was chosen that effectively filters particles 0.1 mm and larger.

Filtering efficiency of the selected fabric is 73%, and when the fabric was incorporated in a system that allowed for sedimentation of the mixed spoils, efficiencies approached 99.8% (Table 4). These efficiencies were attained even when scraping the upstream side of the fabric to enhance flow rates. Filtering efficiencies will vary according to settlement time, and attempting to filter particles with diameters smaller than 0.1 mm is impractical due to clogging of the fabric and low flow rates. One important use of the silt fence is as a secondary impoundment component in case the weir fails (Fig. 4). This is important in ensuring that the Flats do not become recontaminated in the case of catastrophic weir failure.

Site characterization

With the basics of the retention basin conceptualized and laboratory test results supporting our design considerations, the surface hydraulic conductivity (permeability) at the site had to be characterized. To do this we conducted infiltration tests both in the laboratory and in situ.

Laboratory tests

We hypothesized that the sediments from the dredging operation would quickly clog the voids in the gravel pad and significantly reduce the hydraulic conductivity. It was expected that the subsequent buildup of sediment would further reduce the infiltration rate into the EOD pad. To gain additional insight on the sediment's effect on infiltration, we conducted laboratory tests to determine the hydraulic conductivity of the sediment. The following relationships were used in determining hydraulic conductivity:

H_{avg} = Average height of sediment (cm)
Δt = Elapsed time (sec)
h_1 = Initial head of water at $t = 0$ (cm)
h_2 = final head of water at $t = \Delta t$ (cm)

$$k = \frac{H_{avg}}{\Delta t \bullet \ln \frac{h_1}{h_2}} \cdot \qquad (7)$$

These tests were performed in the sedimentation tube (Fig. 2) on the sediments formed during the previous laboratory sedimentation tests. The results are shown in Table 5 and Figure 10. In all four tests, the hydraulic conductivity initially exceeded 1×10^{-4} cm/s in the first three or four hours and gradually fell to about 2×10^{-5} cm/s within eight to 24 hours. This confirmed our expectation that the sediment itself might not reduce the hydraulic conductivity below the targeted 1×10^{-5} cm/s level.

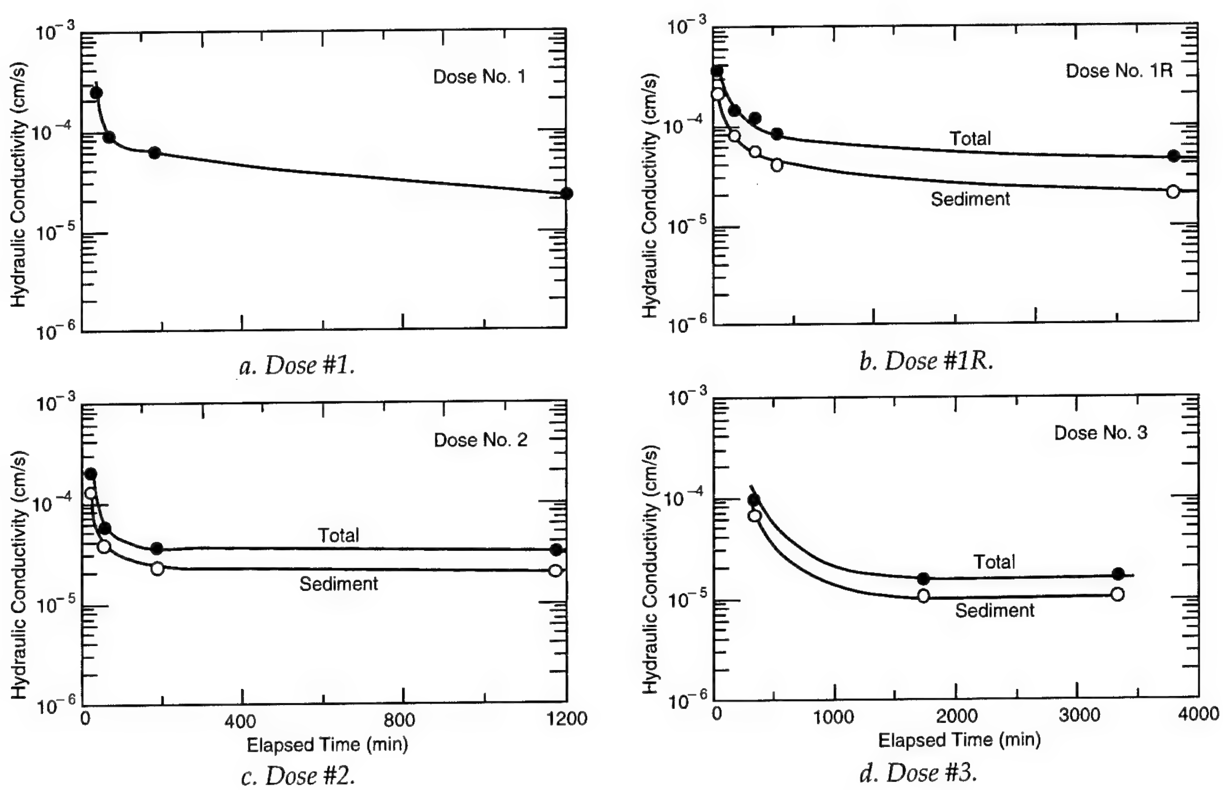
Table 4. System filtering efficiencies using Texel GEO 9 filtering fabric (From Henry and Hunnewell).

Test #	*Geotextile*	*Flow rate [(m³/m²)/min]*	*Final total suspended solids (mg/L)*	*Filtering efficiency: system (%)*	*Retained on #200 (74 µm) sieve (%)*
1	No	DNM*	9249	95.3	DNM*
3	No	DNM*	6360	96.8	1
7	No	DNM*	14466	92.7	3
2	Yes	0.021	654	99.7	<0.1
4	Yes	0.046	1185	99.4	<0.1
6	Yes	0.028	1465	99.3	DNM*

*Did not measure.

Table 5. Laboratory hydraulic conductivity tests on sediment.

Test series number	*Elapsed time (min)*	*Water height (cm)*	*Sediment height (cm)*	*System hydraulic conductivity (cm/s)*	*Sediment hydraulic conductivity (cm/s)*
1 dose of sediment on porous stone					
1	30	37.00	17.7	2.72E-04	2.64E-04
	60	36.65	17.0	9.16E-05	8.87E-05
	180	35.60	15.0	6.46E-05	6.23E-05
	1200	31.80	10.4	2.34E-05	2.24E-05
1 dose of sediment on 13.7 cm of gravel					
1R	20	49.90	31.4	3.70E-04	2.19E-04
	60	49.30	30.3	1.55E-04	8.51E-05
	120	48.60	29.1	1.22E-04	6.43E-05
	165	48.20	28.3	8.78E-05	4.48E-05
	1140	43.50	23.3	4.52E-05	2.06E-05
2 doses of sediment on 13.7 cm of gravel					
2	20	67.70	42.3	2.09E-04	1.42E-04
	55	67.50	41.6	5.91E-05	3.88E-05
	190	67.00	38.3	3.67E-05	2.34E-05
	1170	63.50	33.1	3.41E-05	2.09E-05
3 doses of sediment on 13.7 cm of gravel					
3	334	79.00	41.2	1.01E-04	7.06E-05
	1750	76.50	41.1	1.56E-05	1.00E-05
	3351	73.70	41.1	1.60E-05	1.03E-05



a. Dose #1. *b. Dose #1R.*

c. Dose #2. *d. Dose #3.*

Figure 10. Permeability of sediment in column.

As a result we concluded that some type of liner was required for the settling pond. We briefly investigated the feasibility of using a geosynthetic liner, but cost and availability considerations led us to explore other options to reduce the potential infiltration into the EOD pad. We were made aware of a peaty silt material that was available in abundance near Fort Richardson. This material appeared to have a very high organic content, making it unsuitable for most engineering projects. However, since this material was readily available, we decided to evaluate its suitability as a liner for the settlement pond.

To do this we subjected samples of the peaty silt to compaction and hydraulic conductivity tests in the CRREL laboratories. The laboratory compaction (standard Proctor) and hydraulic conductivity tests were conducted according to ASTM standard methods D 698 and D 5084, respectively. The compaction water contents ranged from about 29% to about 46%, bracketing the initial in-situ (in the borrow pit) water content estimate of about 38%. The results of the compaction tests are tabulated in Table 6 and shown in Figure 11. The optimum water content for the peaty silt material is about 38%, the same as the expected in-situ water content. This result appeared fortuitous, because it meant that we might not have to make a special effort to adjust the water content of the peaty silt.

Laboratory hydraulic conductivity tests were conducted for the same water content regime as the compaction tests. The tests were conducted for effective stress levels of 7, 14 and 35 kPa (1, 2 and 5 psi) to determine the effectiveness of increasing thickness (e.g., increasing stress) as the sediment thickness increases during the dredging operations. The results are tabulated in Table 7 and illustrated in Figure 12. The two tests conducted at 38% and 46% (above optimum) water content showed hydraulic conductivities less than 1×10^{-5} cm/s, the magnitude decreasing with increasing stress level. The results (Fig. 12c) for the test specimen with a water content of about 29% (9% below optimum) did not pass the 1×10^{-5} cm/s litmus test. This was not unexpected, as according to Lambe and Whitman (1969) the hydraulic conductivity for fine-grained soils significantly increases at water contents below the optimum level. The importance of this finding is that the field water content during compaction must be near or above 38%. This appeared to be no problem as the water content in the borrow pit was estimated to be 38%.

Table 6. Laboratory compaction test results for peaty silt.

Sample number	*Water content (%)*	*Dry density (g/cm^3)*
PS-3	28.8	1.116
PS-1	38.2	1.130
PS-2	46.4	1.087

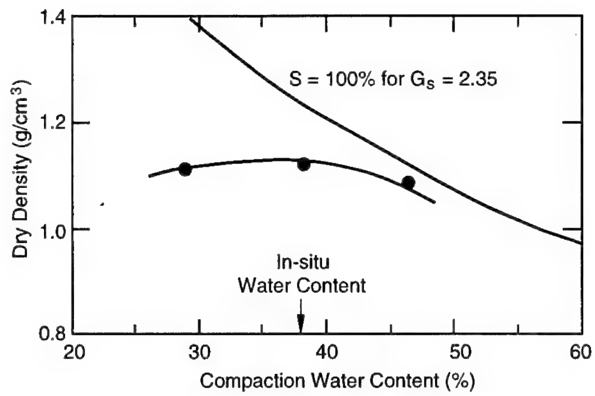


Figure 11. Results of Proctor tests of peaty silt.

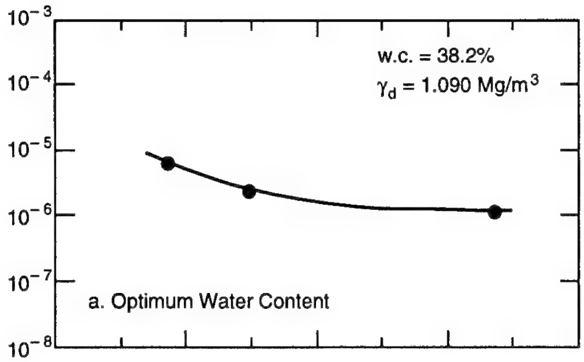
Field tests

The first field tests were conducted in the natural gravel surface of the pad. The second tests were conducted through a layer of sludge obtained from the Eagle River Flats, and a third test through two layers of sludge sediment. A fourth test was performed through a peaty silt layer compacted on the gravel surface inside the test chamber (barrel). Later tests were conducted directly in the peaty silt once it was compacted in the retention basin. The locations of these initial in-situ tests are shown in Figure 13.

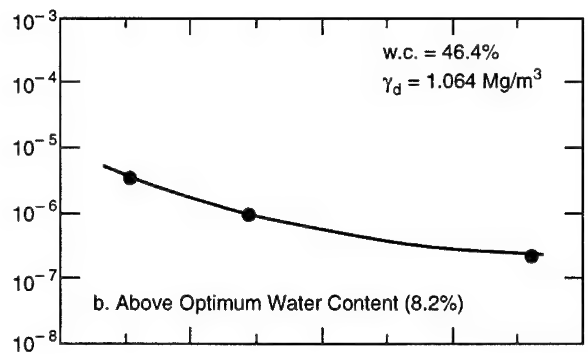
The site for the first series of tests was selected to be representative of the EOD pad. Modified barrels were used for the test chambers. The bottoms of 82.5-L steel barrels, 40 cm in diameter and 64 cm high, were removed and the barrels were set into the test pad as illustrated in Figure 14. The barrels were set into circular channels cut carefully into the pad to about a 15-cm depth. The annular space between the outer barrel walls and the gravel was backfilled with a wet mixture of sand and bentonite clay to prevent leaking of the water placed in the barrel for the infiltration tests. The interior annulus was refilled with a mixture of

Table 7. Laboratory hydraulic conductivity tests for the peaty silt liner material.

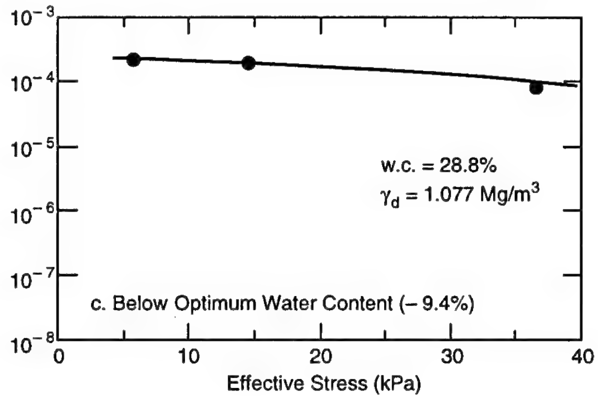
Sample number	*Water content (%)*	*Dry density (Mg/m^3)*	*Effective stress (kPa)*	*Run number*	*Measured hydr. cond. (cm/s)*	*Test temp. (°C)*	*Corrected hydr. cond. (cm/s)*	*Avg. hydr. cond. (cm/s)*	*Avg. effective stress (kPa)*
PS-1	38.2	1.090	9.1	1.00	7.09E-06	22.8	6.57E-06	6.588E-06	8.5
	(optimum		7.9	2.00	7.33E-06	22.8	6.80E-06		
	water		8.6	3.00	7.12E-06	22.8	6.61E-06		
	content)		8.2	4.00	6.84E-06	22.6	6.37E-06		
			14.6	1	2.81E-06	22.7	2.61E-06	2.49E-06	14.6
			14.6	2	2.72E-06	22.7	2.53E-06		
			14.6	3	2.48E-06	22.8	2.31E-06		
			14.5	4	2.67E-06	22.6	2.49E-06		
			33.6	1	1.40E-06	22.6	1.30E-06	1.14E-06	33.5
			33.9	2	1.25E-06	22.6	1.16E-06		
			33.5	3	1.16E-06	22.6	1.08E-06		
			32.8	4	1.08E-06	22.6	1.01E-06		
PS-2	46.4	1.064	6.4	1	5.26E-06	23.0	4.86E-06	3.66E-06	4.8
	(optimum		4.7	2	3.53E-06	23.0	3.26E-06		
	water		4.0	3	3.70E-06	23.1	3.41E-06		
	content		4.0	4	3.38E-06	23.1	3.12E-06		
	+8.2%)								
			13.2	1	1.42E-06	23.3	1.30E-06	1.03E-06	13.8
			13.3	2	1.29E-06	23.2	1.19E-06		
			14.4	3	9.50E-07	23.3	8.71E-07		
			14.3	4	8.15E-07	23.2	7.49E-07		
			35.5	1	3.29E-07	22.3	3.09E-07	2.35E-07	35.4
			35.4	2	2.38E-07	22.5	2.23E-07		
			35.4	3	1.45E-07	22.6	1.35E-07		
			35.4	4	2.94E-07	22.6	2.74E-07		
PS-3	28.8	1.077	5.4	1	2.46E-04	23.7	2.24E-04	2.41E-04	5.4
	(optimum		5.4	2	2.63E-04	23.7	2.39E-04		
	water		5.4	3	2.59E-04	23.7	2.36E-04		
	content		5.4	4	2.93E-04	23.7	2.66E-04		
	–9.4%)								
			14.2	1	2.25E-04	23.7	2.04E-04	2.04E-04	14.2
			14.2	2	2.27E-04	23.7	2.06E-04		
			14.2	3	2.37E-04	23.7	2.15E-04		
			14.2	4	2.11E-04	23.7	1.92E-04		
			36.1	1	1.09E-04	22.4	1.02E-04	9.70E-05	36.1
			36.1	2	9.98E-05	22.4	9.35E-05		
			36.1	3	1.01E-04	22.4	9.46E-05		
			36.1	4	1.04E-04	22.4	9.76E-05		



a. Optimum water content.

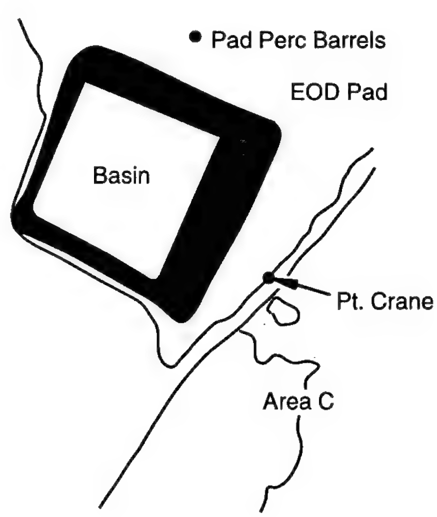


b. Above optimum water content.



c. Below optimum water content.

Figure 12. Results of laboratory permeability tests.



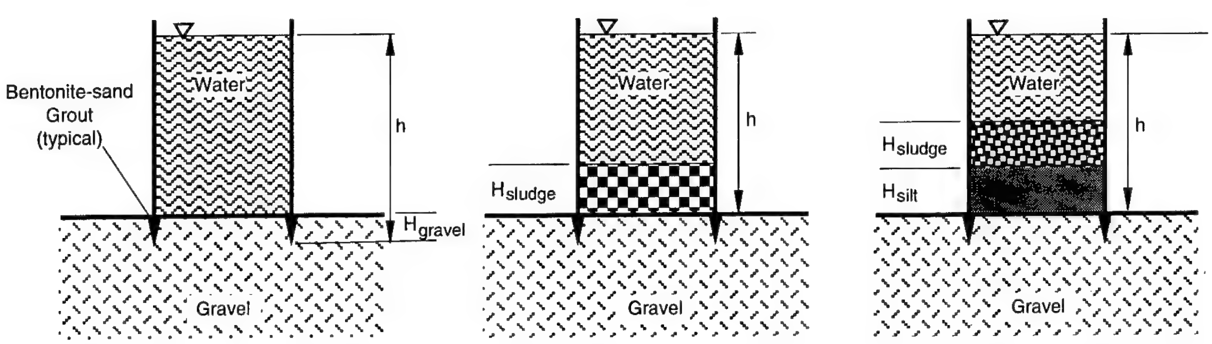
a. Location of tests on the EOD pad.

Figure 13. Hydraulic conductivity barrel test cells on the EOD pad.

b. Test site.

Figure 13 (cont'd). Hydraulic conductivity barrel test cells on the EOD pad.

native gravel and sand. To estimate the hydraulic conductivity of the bare gravel pad without either the sediment or the peaty silt liner, the barrel (Fig. 14a) was filled with water obtained from Eagle River Flats (near the edge of the EOD pad) to a depth of about 30 cm. This water was allowed to soak into the pad to saturate the gravel beneath the test barrel. Water was then added until the infiltration rate was about constant. The barrel was then filled again with water to the 30-cm level and the rate of infiltration into the test pad was measured. To estimate the hydraulic conductivity of the ERF sediment on the gravel surface of the EOD pad, water from the Flats was placed in the barrel



a. Water on gravel (unmodified pad). *b. Sediment on gravel.* *c. Sludge on peaty silt.*

Figure 14. Schematics of barrel tests on EOD pad.

to soak the gravel, and then a mixture of four parts water to one part wet sediment was poured into the barrel and allowed to settle overnight. The barrel (Fig. 14b) was then filled to a depth of about 30 cm and water from the Flats was used to estimate the hydraulic conductivity of the sediment. To determine the effectiveness of peaty silt in limiting the infiltration of water into the gravel pad, a layer about 14 cm thick was compacted directly on the gravel inside a test barrel (Fig. 14c). A water–sediment mixture was then poured into the barrel over the peaty silt and allowed to settle. The hydraulic conductivity was then estimated using the same procedures as for the first two barrel tests.

The infiltration rates in the EOD pad barrel tests were used to estimate the hydraulic conductivity of the gravel, the sediment, and the peaty silt. The hydraulic conductivity (k_{est}) was estimated using Darcy's equation for laminar flow:

$$q = ki \tag{8}$$

where

q = the velocity of flow (cm/sec)
i = the hydraulic gradient (= h/H)
h = the pressure loss across the sample (cm)
H = the thickness of the sample (cm).

The infiltration tests on the EOD pad were conducted with a falling head, i.e., the elevation of the water surface fell during each test. The resulting solution for the hydraulic conductivity for a test with a falling head is

$$k = \frac{H}{\Delta t} \ln \frac{h_1 - h_0}{h_2 - h_0} \text{ (cm/sec)} \tag{9}$$

where

Δt = time interval between making the h_1 and h_2 readings (sec)
h_1 and h_2 = water elevation heads at the start and end of the test (cm)
h_0 = water pressure head at the bottom of the barrel (cm).

For the percolation tests in the barrel tests, the k value determined is an estimated value because the pressure head at the bottom of the barrel is indeterminate. We assume that the water is free-draining at the bottom of the barrel (in the gravel) and the water pressure is zero at the bottom of the barrel, i.e., $h_0 = 0$. Thus, eq 9 is reduced to

$$k_{est} = \frac{H}{\Delta t} \ln \frac{h_1}{h_2} \text{(cm/sec)}. \tag{10}$$

Figure 14 illustrates how h_i and H for each of the barrel tests were measured.

The EOD pad barrel percolation test results are shown in Figures 15 and 16 and Table 8. Figure 15 shows that the estimated hydraulic conductivity for the bare gravel pad was in the range of 1×10^{-2} to 1×10^{-3} cm/s, very high as we expected. This result validated our assumption that the water pressure at the bottom of the barrels in the gravel pad was roughly zero. One dose of sludge (sediment–water mixture) reduced k_{est} to less than 1×10^{-3} cm/s and a second dose further decreased k_{est} to about 1×10^{-4} cm/s, still short of reaching the target level of 1×10^{-5} cm/s. Figure 16 shows that a layer of compacted peaty silt will help achieve that goal. In this case the sludge was poured over the peaty silt in the bottom of the barrel. The resulting estimated hydraulic conductivity was about 4×10^{-6} cm/s. This result validated the laboratory observations for the peaty silt.

To further substantiate these positive results, barrel infiltration tests were also conducted directly on the compacted peaty silt liner in the retention basin. The locations of these tests are shown in Figure 17. The peaty silt was compacted with several passes of a smooth vibratory drum roller on a loose lift about 25 cm thick. The water contents and dry densities for each of the test locations are given in Table 9. The barrels were installed in the peaty silt liner as shown in Figure 18. We conducted one test with just Flats water in the barrel and found the hydraulic conductivity of the peaty silt to be just slightly greater than 1×10^{-5} cm/s (Fig. 19, Table 10). At two other locations we used a sludge mixture as the permeant. Figure 19 shows that with a sediment–water mixture similar to that expected from the dredging operation, the hydraulic conductivity was reduced to 1 × 10–5 cm/s. Furthermore, it continued to decrease with time.

The hydraulic conductivities obtained from field test results with the peaty silt are slightly greater than the results obtained for low stress in the laboratory. The reason for this is that the water content in the field was much higher than expected, about 60% rather than 38%. This can be seen in Figure 20, where the hydraulic conductivities and dry densities are plotted versus the water contents for both the laboratory and the field tests. The higher-than-expected water content is probably due to the considerable rainfall that occurred after the peaty silt was stockpiled in the basin area. Nonetheless, the goal of achieving a hydraulic

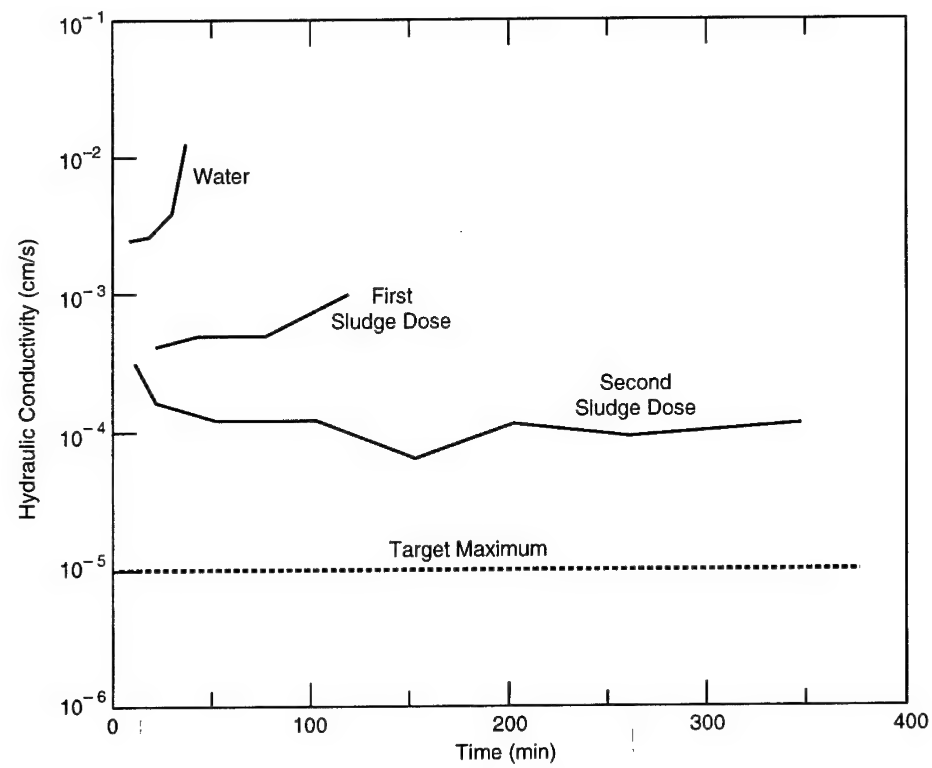


Figure 15. Results of barrel infiltration tests for unaltered and sedimented pad.

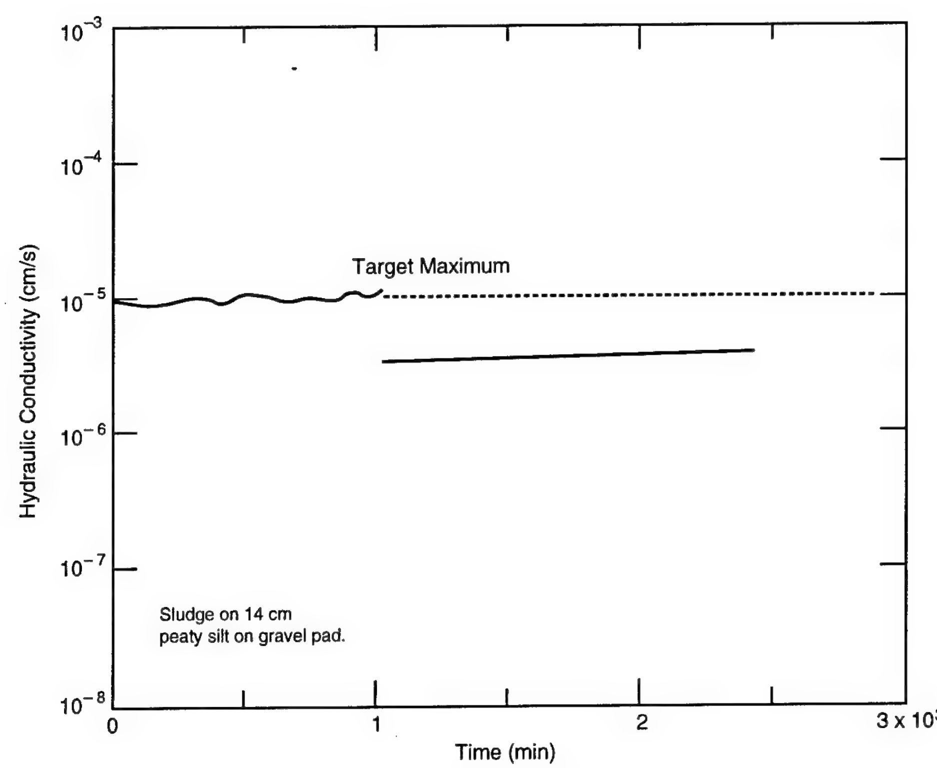


Figure 16. Results of barrel infiltration tests for sludge on peaty silt.

Table 8. Field percolation tests.

Time (min)	Height of water (in.)	Flow rate (cm^3/s)	Hydraulic conductivity (cm/s)
Perk tests with water on gravel			
0	6.00		
10	3.00	15.46	3.18E-03
0	6.00		
10	3.50	12.88	2.51E-03
0	6.00		
10	3.88	10.95	2.05E-03
0	6.00		
10	3.88	10.95	2.05E-03
0	6.00		
10	3.88	10.95	2.05E-03
0	6.00		
10	3.75	11.60	2.20E-03
20	2.25	7.73	2.38E-03
30	1.13	5.80	3.18E-03
38	0.00	7.25	1.19E-02
Water on first sludge dose on gravel			
0	7.00		
20	6.00	2.58	3.66E-04
40	5.00	2.58	4.33E-04
60	4.13	2.25	4.57E-04
80	3.41	1.85	4.55E-04
100	2.63	2.01	6.17E-04
120	1.78	2.17	9.12E-04
Water on second sludge dose on gravel			
0	8.25		
10	7.75	2.58	2.98E-04
20	7.50	1.29	1.56E-04
50	7.00	0.86	1.09E-04
100	6.25	0.77	1.08E-04
150	5.88	0.39	5.89E-05
200	5.28	0.61	1.01E-04
250	4.81	0.48	8.85E-05
300	4.38	0.45	9.07E-05
350	3.91	0.48	1.08E-04
Water on first sludge dose on peaty silt			
1	15.88		
1023	15.63	0.013	3.62E-06
2418	15.25	0.014	4.05E-06

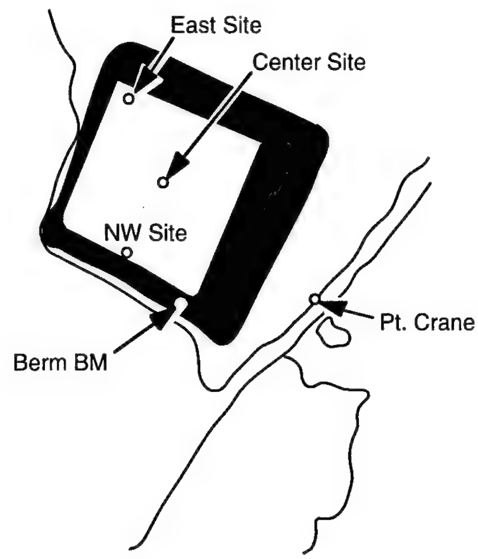
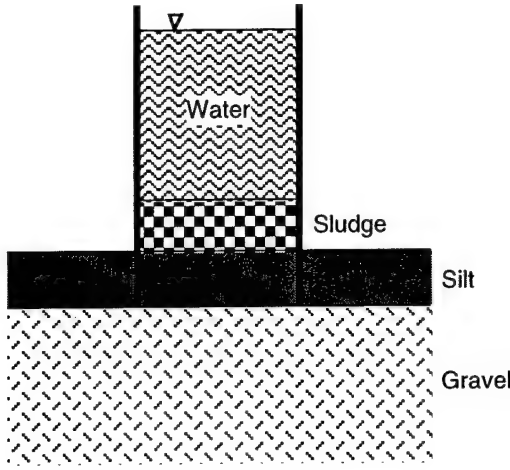


Figure 17. Retention basin barrel infiltration and permeability test locations.

Table 9. Field compaction test results for peaty silt.

Sample number	Water content (%)	Dry density (g/cm^3)
PL-1	58.3	0.915
PL-2	60.8	0.891
PL-3	55.2	0.917

a. Schematic of cell.



b. Test site.

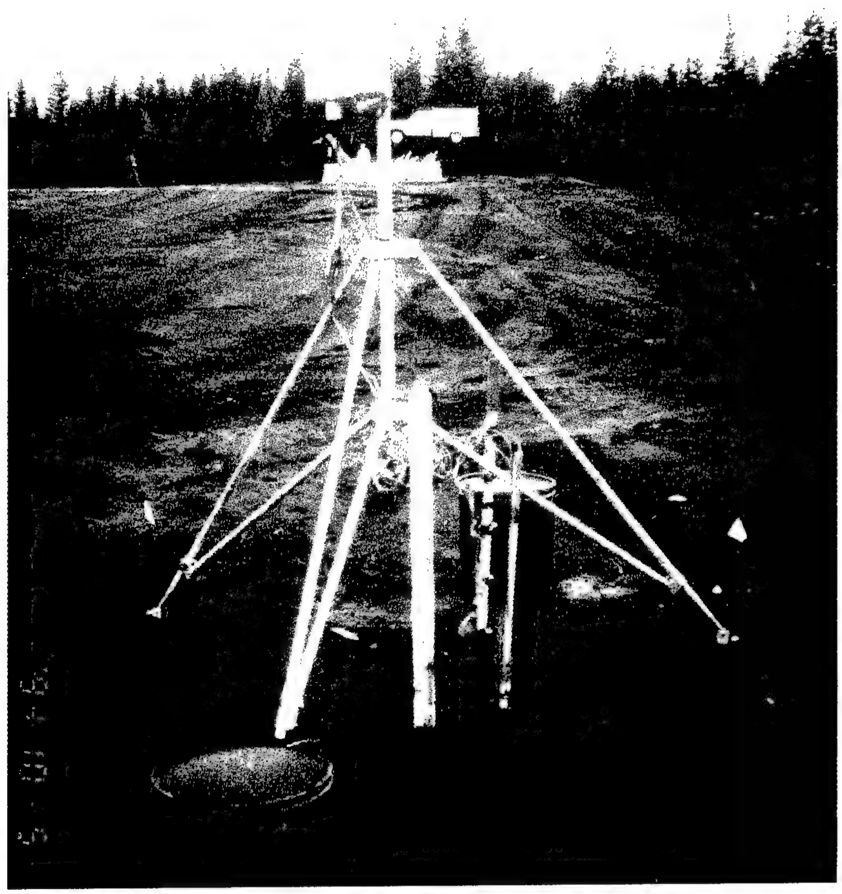


Figure 18. Barrel infiltration test cell in retention basin.

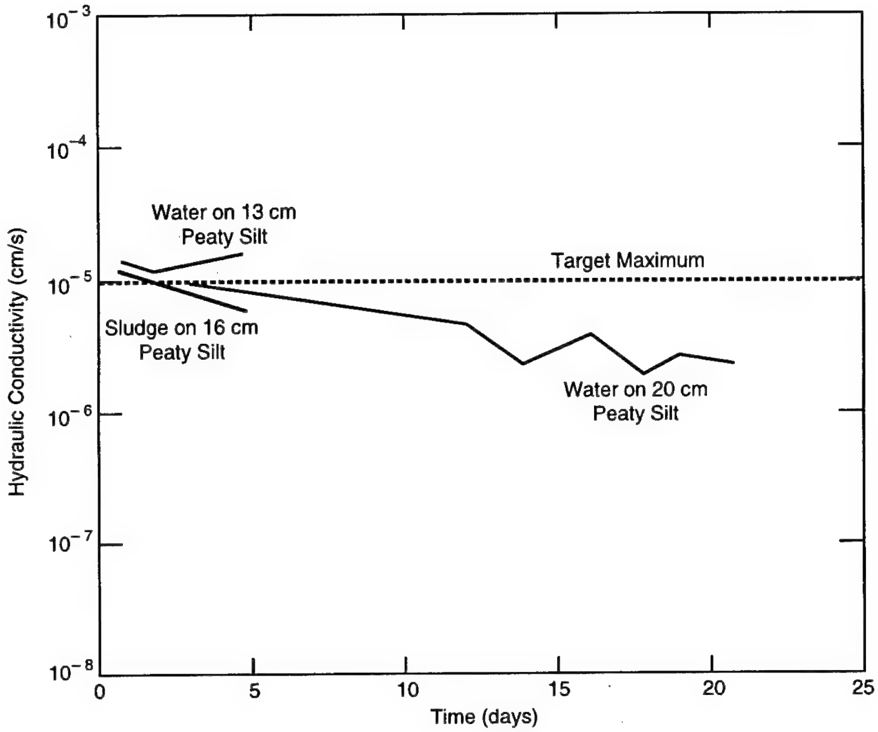
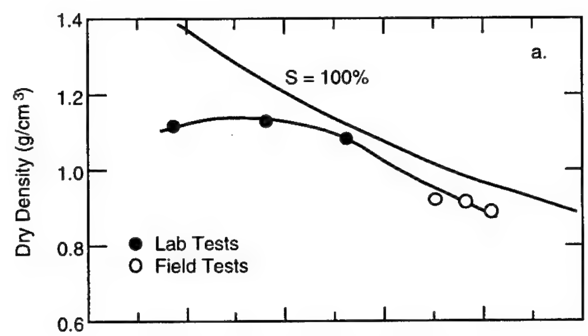


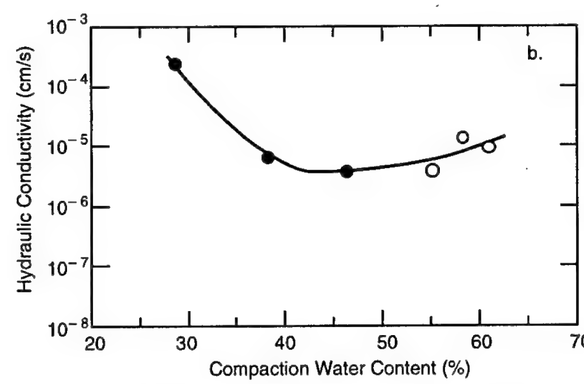
Figure 19. Results of barrel infiltration tests for sediment on peaty silt liner.

Table 10. Field infiltration tests in basin liner.

Time (min)	*Height of water (cm)*	*Hydraulic conductivity (cm/s)*
Water on 13 cm peaty silt on gravel in basin		
0	15.75	
1118	14.63	1.40E-05
2496	13.50	1.23E-05
6961	9.50	1.67E-05
Sludge on 16 cm peaty silt on gravel in basin		
0	10.50	
1117	10.00	1.20E-05
2495	9.50	1.02E-05
6960	8.63	5.95E-06
Water on 20 cm peaty silt on gravel in basin		
0	15.00	
4460	13.25	9.42E-06
17765	11.00	4.74E-06
20269	10.80	2.48E-06
23515	10.40	3.94E-06
26005	10.25	1.98E-06
27750	10.10	2.86E-06
30510	9.90	2.45E-06



a. Dry density vs. water content.



b. Hydraulic conductivity vs. water content.

Figure 20. Composite of lab and field permeability test results for peaty silt.

Table 11. Retention basin model results summary.

System characteristic	Drainage: Pad	Drainage: Weir
Cumulative totals in cubic meters	969	17,684
Equivalence in cm of water/year	12	218.5

conductivity of 1×10^{-5} cm/s or less in the basin area with the peaty silt as a liner is achievable. Figure 20b shows that as long as the water content is in the range of about 38–60%, the peaty silt will provide the desired protection against infiltration. At water contents below 38% the hydraulic conductivity of the peaty silt increases significantly, much as would be expected.

Model calculation

A model was then constructed and data from the preceding tests input to determine feasibility of the design (Appendix B). One important factor in the determination of the adequacy of the design is the additional water that will be percolating through the pad because of the retention basin. In Anchorage, average yearly precipitation is equivalent to 38.7 cm of water. Table 11 shows the results of the model for dredging a 0.8-ha site over an eight-day period. As is indicated, the amount of water that will pass through the basin into the EOD pad is about one quarter what would normally pass through the pad through natural precipitation. This model, as well as the results of the tests done on the physical characteristics of the EOD pad and retention basin materials, indicated that the basin as designed would satisfy the requirements of the RPMs as well as be feasible for the pilot dredge program. The RPMs thus approved the use of the EOD pad for the dredge spoils retention basin.

SITE PREPARATION

Prior to deployment of the dredge, much site preparation and construction work needed to be carried out. Among the major projects were construction of the retention basin and its associated structures, the drop inlet structure and inflow pads; a road from the EOD pad to Clunie Creek, where the dredge was to be deployed into the

Figure 21. Retention basin berms.

Figure 22. Spoils line outlet pads.

Flats; a pad at Clunie Creek where deployment would be based; and setting up the cable traverse system for guiding the dredge during dredging operations. Assistance from several entities, including the DPW, Roads and Grounds at Fort Richardson, and several military functions, was critical in the completion of these tasks.

The largest project was the construction of the retention basin, where spoils from the dredging operation are pumped for decantation and treatment. The retention basin is a 0.78-ha earthen structure constructed of compacted gravel and lined on the bottom and inner sides with a 15- to 20-cm-thick compacted layer of peaty silt. The berms encircling the basin are 2 m high with 2:1 interior and 3:1 exterior slopes. The tops of the berms are approximately 2.5 m wide (Fig. 21). The interior face of the berms are lined with two layers of peaty silt sandwiching an erosion control geotextile fabric. Two 8-m-square concrete pads for spoils outflow are located 3 m off the northwest berm near the north and west corners of the basin. Jersey barriers are placed in a staggered chevron pattern to break the flow of the spoils into the basin. The pads are surrounded by chain-link fence on three sides to contain any passed-through ordnance and to restrict access to the pads (Fig. 22).

A drop inlet structure located at the south corner of the basin is used for decanting the supernatant back to the Flats after settling (Fig. 4). The structure consists of an adjustable weir, a filtering fence 2 m behind the weir, and a 1.2-m ø drop inlet 1.4 m behind the fence. The drop inlet connects to a 0.6-m ø corrugated culvert that empties out in a highly vegetated section of Area C in the Flats.

Construction of the basin was initiated in July of 1994. Due to the hazardous conditions, the work was performed by the Roads and Grounds section of the DPW with help from other support functions at Fort Richardson. Originally, the existing berms on the EOD pad were to be utilized as part of the retention basin, but these were found to be unsatisfactory by the site engineer. As work progressed and equipment operators became more familiar with the site and its associated hazards, additional changes were made in the basin design and construction. The northeastern section of the basin area was heavily used for ordnance disposal and detonation in the 1950s. When the operators tried to level the area using cut and fill (the corner

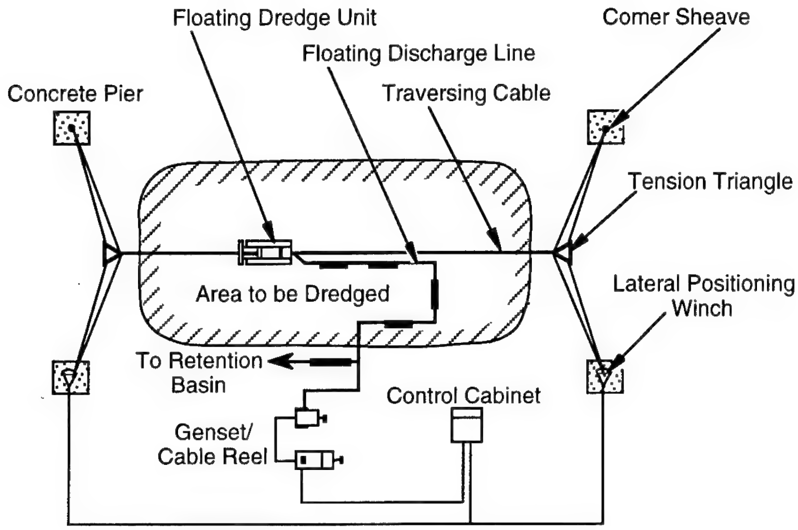


Figure 23. Dredge traverse system.

was ≈ 3 m higher than the opposite corner), some small-caliber ordnance detonated and operations were halted. Leveling recommenced under a new strategy: filling the low end of the basin floor with trucked-in material. Throughout the construction process, changes to the system were necessary due to additional requirements pertaining to the RCRA status of the site. By September, the final design was approved and construction wrapped up in time for the initiation of dredging.

In addition to the construction of the basin structure, the Roads and Grounds office was tasked with the construction of a road through the wooded area between the EOD pad and Clunie Point, on the southern side of Clunie Creek where it meets the Flats. A cul-de-sac large enough to turn a full-size tractor-trailer was required at the end of the road. A gravel ramp to Clunie Creek, the deepest water easily accessible to vehicle traffic, was installed to facilitate placement of the dredge in the Flats. These areas are referred to in this report as Clunie Pad. Geotextile was laid over the area used for the pad prior to graveling due to the wet, spongy nature of the ground in this area. Prior to deployment, EOD personnel swept the area for UXOs to reduce the ubiquitous hazards posed by munitions.

With construction of the shore-based structures drawing to a close, the tasks associated with the actual operation of the dredge system were begun. Primary among these tasks were the construction and deployment of concrete piers or deadweights for the dredge traverse system (Fig. 23). Guidance on weight and configuration of these items was difficult to obtain. In most cases, lateral cable systems are braced to trees along the shoreline. This was not possible at the Flats. A decision was made to use cubic meter concrete deadweights with provisions for lifting and attaching lateral cable components on the top of each block. (Each weighs approximately two tons.)

The layout for the blocks was determined from previous sampling of the area and reports of waterfowl mortality during feeding. Locations for the placement of the deadweights were surveyed in from a temporary benchmark located on the northeast corner of Clunie Pad using a total station and marked with stakes and flagging. UH-60 helicopters were used to place the deadweights at their designated points. A UH-1 helicopter was then used to assist in retrieving the sling gear. Initial tightening of the lateral winch cables indicated that a single block was not sufficient in the Flats due to the lubricity of the mud and vegetation as well as the unstable footing, so the blocks were doubled up and cinched together.

With the deadweights in place, the remainder of the support equipment was assembled. The lateral winch and cable system was installed at the first location off the mouth of Clunie Creek. The spoils line, consisting of 12-m sections of PE pipe, was run from the edge of Clunie Creek, up the road towards the basin, through the woods, and up over the berm to the northern outflow pad. Equipment and spare parts were assembled on Clunie Pad.

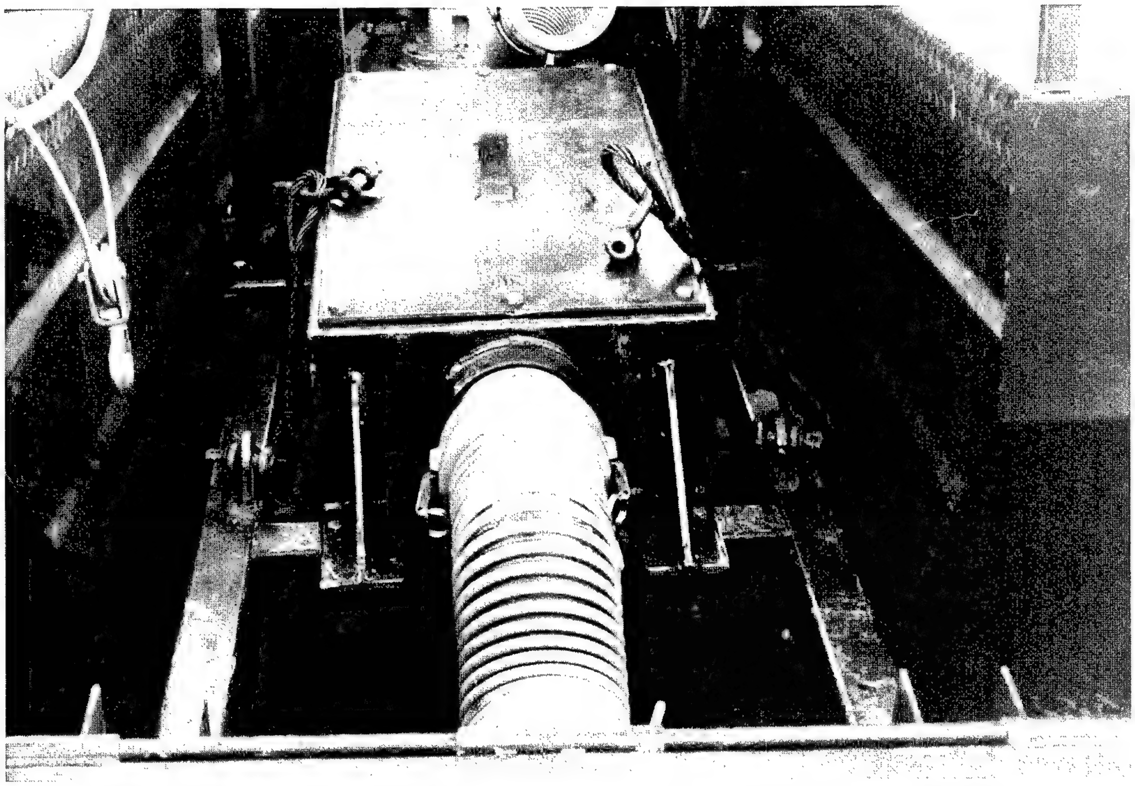


Figure 24. Ordnance retention receptacle.

After much work on the equipment, all systems were integrated and operational. A last-minute requirement that a box be placed between the dredgehead and pump delayed initiation of dredging for about a week. The device, called a "boom box" (Fig. 24), reduces the velocity of the flow over a length of about 1.2 m up to a factor of seven. The theory is that heavier objects, such as mortar rounds, will drop out before reaching the pump. A self-dumping feature was built in to allow disposal of any collected debris.

INSTRUMENTATION AND SAMPLING

Several parameters related to the dredging process need to be monitored to ensure that the process is effective and that there is no collateral contamination occurring due to dredging activities. Process efficacy can be determined by sampling of the spoils and the retention basin sediments. Pond recontamination due to dredging is a more difficult parameter to measure because of the extremely hazardous nature of the operation. The most obvious area that may become contaminated is near the dredge during dredging operations. Unfortunately, the area around the dredge must be evacuated while actively dredging. Post-dredging sampling is the only current method of measuring dredge area contamination. This is being done by other researchers (Lawson and Brockett 1993) and thus will not be discussed here. However, at the outflow from the basin, effluent can be sampled and contaminant levels measured.

The best method of determining whether the dredge is removing WP from the Flats is to analyze material that is being pumped to the retention basin. Due to safety considerations, material within the basin cannot be sampled during active dredging and no sampling can easily occur on the dredge, so a tap was put into the spoils line just below the top of the berm (Fig. 25). This tap consisted of a pitless adapter, a ball valve, and a 1-m length of 1/2-in. (1.27 cm) Tygon tubing. A 5-gal. PE bucket was used to collect spoils for integrated samples, which were collected hourly. Storage of samples was simplified due to the low ambient temperature: it did not get above 7°C during dredging operations. Samples were shipped overnight to CRREL upon cessation of operations for analysis there. A standard operation procedure for sample collection and storage is included in Appendix C.

To measure the basin parameters that will af-

Figure 25. Dredge spoils sampling station.

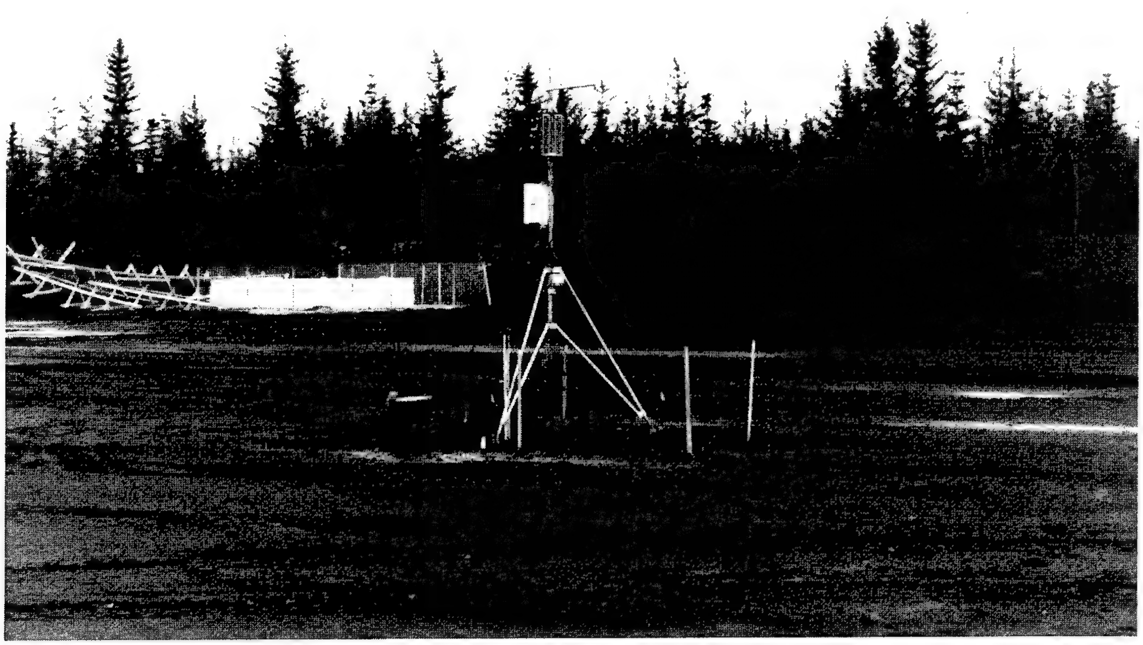


Figure 26. Retention basin instrumentation station.

fect the natural remediation of the WP, four solar-powered instrumentation stations were erected (Fig. 26). Each station contains a rechargeable 12-V power supply, a Campbell CR-10 datalogger, an SM-716 storage module, a four-sensor thermistor string, and a four-sensor moisture block string. Temperature and moisture content are two factors that greatly influence the sublimation process of white phosphorus and thus must be monitored to evaluate remediation efficiency.* In addition to the standard sensor suite, one instrumentation station, located in the center of the basin, has an ultrasonic water level gauge and an air temperature sensor. The water level sensor is a Campbell Model UDG01 Ultrasonic Depth Gauge, which incorporates a Polaroid ultrasonic transducer and model 6500 sonar ranging module. It is mounted on an arm located about 2.5 m above the original basin bottom. The air temperature sensor is a Campbell Model 701 thermistor sensor mounted in a gilled enclosure. Air temperature and spoils level are monitored as part of the remediation process within the basin.

Outflow of the supernatant is monitored to ensure that the Flats are not being recontaminated by the dredging process. After passing over the weir and through the filtering fence, the supernatant is sampled for later analysis for WP contamination. During the 1994 field season, the amount of spoils pumped into the retention basin was insufficient to accumulate sufficient supernatant to pass through the drop inlet structure, and thus no samples were taken. The standard operation procedure for this sampling is described in Appendix D for further reference for the 1995 field season. The possible availability of a mobile field lab and the use of fiber-optic headspace analysis will make sample storage and processing much simpler and more reliable.

The last monitoring instrument directly related to the dredging operation is a Hydrolab station located at Canoe Point. The Hydrolab is connected to an instrumentation station similar to those located in the basin. The addition of the Hydrolab enables the measurement of water quality parameters such as dissolved oxygen, pH, conductivity, salinity, temperature and depth. This station will give a good indication of the dredge's effect on the surrounding pond. Although this station was installed and operating during the dredging operation, time limitations and equipment problems prevented dredging in the area adjacent to the Hydrolab, so it was not directly affected. However, the data collected can be utilized as baseline data for comparative purposes for next year's work.

In addition to these sensors and the related sampling and analysis, several other studies interleaved with the dredging project to determine impact and the efficacy of this remediation strategy. Invertebrate sampling in the area to be dredged was conducted by Carl Bouwkamp of AEHA, and a vegetation survey was conducted in this area by Charles Racine of CRREL. Marianne Walsh, also of CRREL, obtained and analyzed surface sediment samples to indicate the degree of contamination of the area to be dredged (Racine et al. 1993). Work by Dan Lawson in relation to physical systems processes will indicate redeposition of sediments caused by dredging and natural processes.

A study planned for this season to determine the effectiveness of the remediation strategy for the retention basin was not conducted due to the small volume of spoils generated during this year's abbreviated dredging season. This study will be conducted next year in association with Marianne Walsh's remediation work.

DREDGING ACTIVITY

Prior to commencing active dredging activities, a series of pumping tests was conducted to qualitatively determine the operating parameters of the dredging system. In these tests, we pumped clear water through the spoils line to the retention basin. Due to changes in basin design to address concerns of the RPMs, the vertical head of the system is about 3 m greater than the dredge specifications indicated. This greatly affects dredge performance and thus tests were conducted to ensure the system would perform adequately for our needs. The pump tests also were used to check the spoils line for weak points and to indicate the effect the boom box would have on dredge operation. Line pressures and system performance can be indicated only from pumping water, because when spoils are pumped, the density of the material increases, thus decreasing flow rate while increasing line pressure. Fundamental fluid dynamics relationships for dredging illustrate this (Huston 1970):

$$SG = \rho/1000\ (\mathrm{kg/m^3}) \tag{11}$$

*M.E. Walsh, Applied Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.

$$Q_s = 36.8\,(P_h)/SG\,(\Sigma h_i)\ (\mathrm{m}^3/\mathrm{hour}) \qquad (12)$$

$$p_h = (\Sigma h_i)\,(SG)\,(9.806)\ (\mathrm{Pa}) \qquad (13)$$

where

SG = specific gravity
ρ = fluid density (kg/m^3)
Q_s = flow rate
P_h = power (kW)
h_i = head components (kg)
p_h = line pressure.

Even these relationships give only an indication of the system performance due to the vagaries of actual production, such as variable spoils ratio, fluctuating line velocities, and variable friction head losses.

Active dredging commenced on 15 October following completion of pumping tests. Dredging was restricted to the mouth of Clunie Creek adjacent to the ramp leading into the creek and out towards the point diagonally across the inlet. Dredged depth was 70–100 cm from the water surface, with dredged width of 2.5 m. The dredge removed material from a traverse approximately 35 m long. Dredging occurred over a period of two days, with a total of about three hours of actual material removal occurring. Problems with flexible hose connections and the loss of suction due to dredge modifications (boom box) limited dredging activities, and the onset of winter on the 16th terminated operations (Fig. 27).

During the active dredging, two samples were obtained from the spoils line tap for future analysis. One sample was taken during each day's pumping. Spoils outflow was also monitored from behind the berm. A camera onboard the dredge also recorded the process at the dredgehead. Some suspended sediment in the vicinity of the dredgehead was evident when pumping problems occurred, but the water quickly cleared when pumping resumed. Observations at the spoils line outflow pad indicate that a large amount of bottom vegetation was present in the area dredged. Production rates were not measured and cannot be estimated, as personnel had to be below the top of the berm. The ratio of solids to supernatant in the samples taken from the spoils line was our only indication of production rate. The ratio in these samples was ≈ 10:1 water to soil.

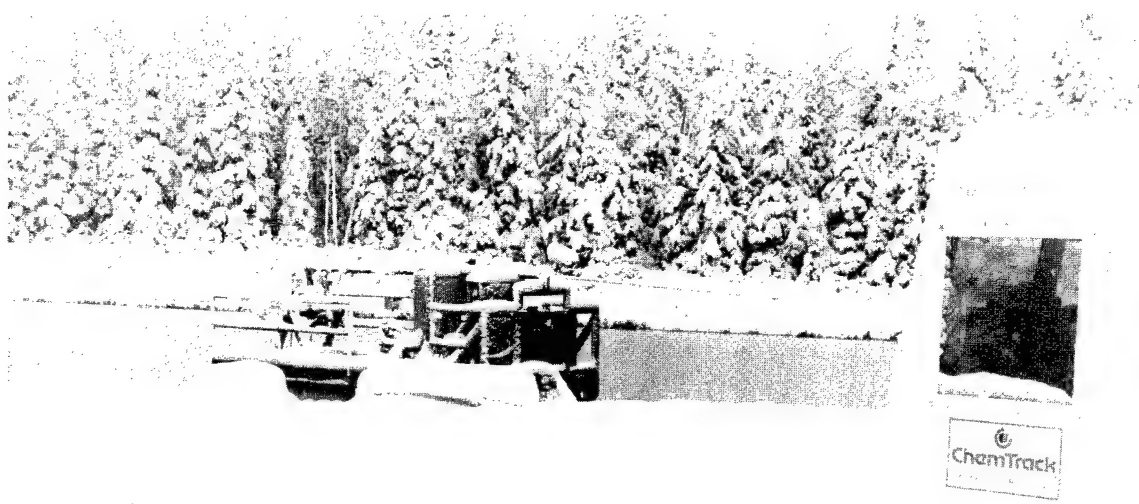


Figure 27. Cessation of dredging activities.

RESULTS

Analysis of spoils samples

Two 500-mL samples from the spoils line were obtained, one from each of the two days on which dredging took place. These samples were analyzed at CRREL using an SRI gas chromatograph. Analyses were performed by Marianne Walsh. The first sample, taken on the 15th of October, indicated no white phosphorus present. The second sample was highly contaminated, with a concentration of 2.7 µg/g, or 5843 µg/L. This sample had to be diluted 500:1 to read on scale on the instrument. For comparison, the WP calibration standard concentration is 73 µg/L. This indicates that a highly contaminated area in Clunie Inlet was dredged. A comparison of chromatograms is shown in Figure 28.

There was no outflow of supernatant through the weir due to dredging activity, so no samples were taken for analysis. On the 19th, some flow through the filter fabric on the weir as well as through the filter fence due to snowmelt did occur, but no sampling was conducted as sampling equipment and containers had been put into storage for the next season.

Data from stations

Data from the four basin stations and the Hydrolab were collected over the period 5–19 October and 8–19 October, respectively. These data are not important to this year's work due to the limited amount of dredging that occurred. In addition, a 20-cm snowstorm on the 16th biased the Hydrolab data as well as the basin level readings. The most interesting data are temperature data, as they indicate the conditions under which dredging was conducted. Figure 29 is a graphical representation of pertinent data from these stations.

Estimated dredged material quantity

An estimation of the material dredged is problematic due to the constraints imposed by the Safety Plan. However, we can get a rough estimate from the approximate area dredged. Using the numbers stated above, a total of about 52 m^3 of material was removed from Clunie Inlet. An estimate of the mass of white phosphorus cannot be made from the limited amount of data obtained. With the resumption of dredging activity next spring, a larger database may allow a calculation of mass flow or quantity of WP removed.

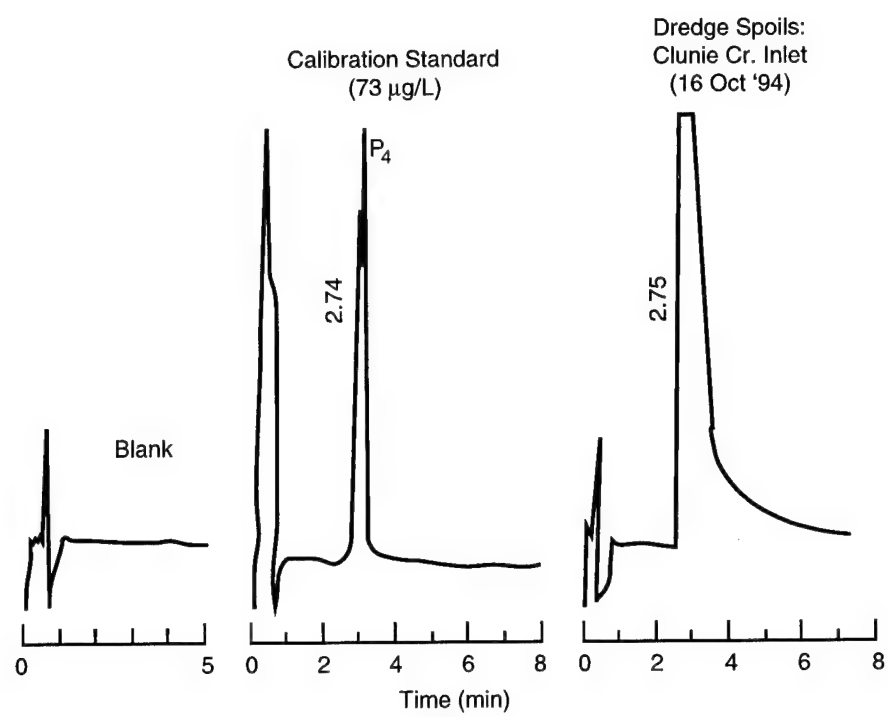
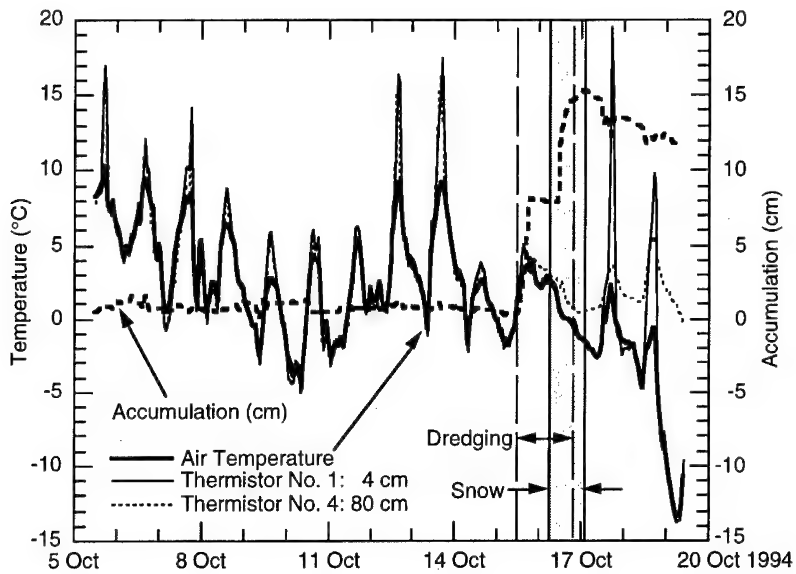
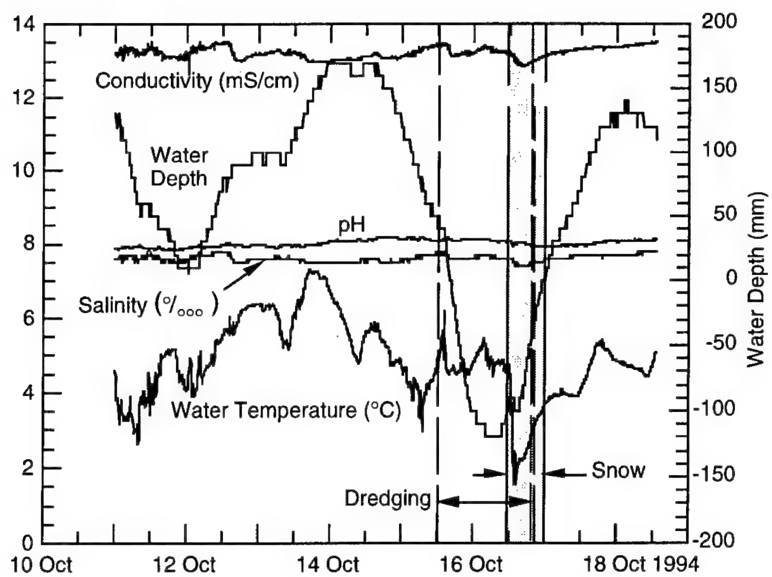


Figure 28. Comparative chromatograms for spoils analysis.



a. Temperature profiles and level data from basin stations.



b. Canoe Point Hydrolab data.

Figure 29. Data from instrumentation stations.

DISCUSSION

The area dredged during the 1994 field season was much smaller than originally planned. Delays in procurement and setup as well as safety concerns pushed the initiation of dredging back to mid-October. Most of the problems were surmounted over the brief season at the end of the fall, but each problem required time, which was not available. The primary goal for this season was to deploy a dredge and remove contaminated sediments from the Flats, depositing them in the retention basin for further treatment, and this we did accomplish (Fig. 30).

Dredging in an active impact area presents many unique problems that can be addressed only

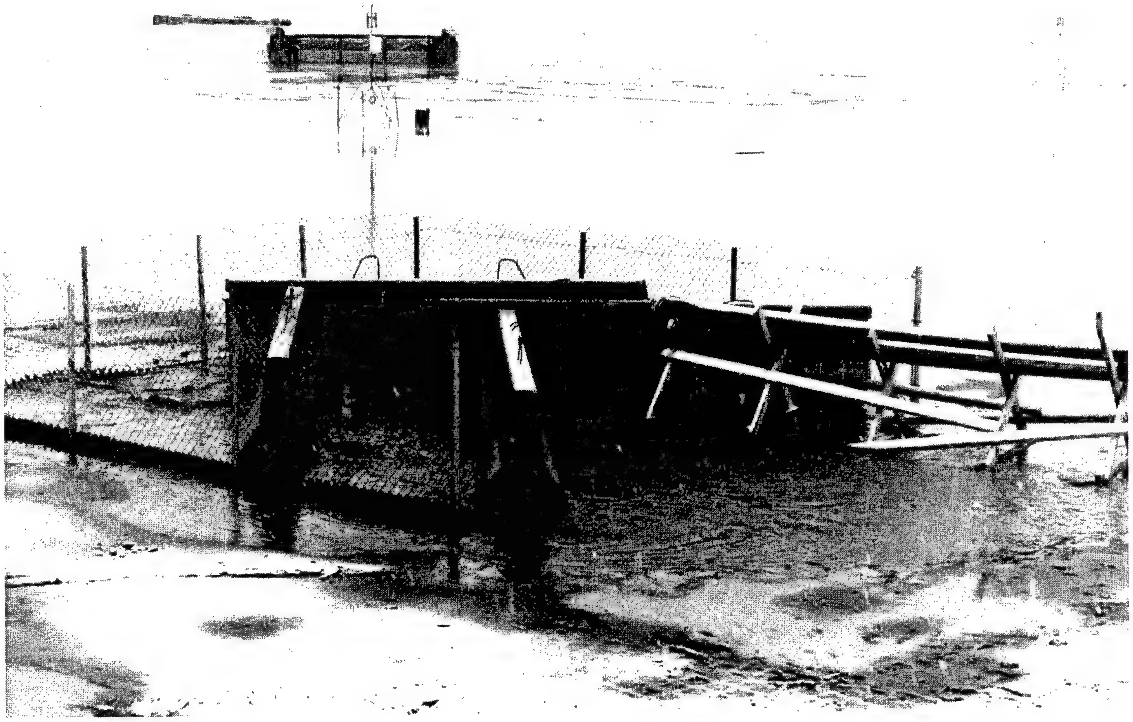


Figure 30. Pumping contaminated spoils from the Flats.

in a deliberate, cautious manner. Experience gained over the course of time will result in increased efficiencies and a loosening of restrictions of personnel activities. Some problems still remain, including developing a Safety Plan acceptable to all parties. The "boom box" between the dredgehead and pump is a major design problem that needs to be addressed before dredging can resume next season. Other problems may arise with further experience with the system.

At this juncture, it is not possible to determine if dredging is a cost-effective method of remediation. It has been shown that dredging will remove WP from the Flats, but no data are available for attenuation in the basin or contamination of the supernatant or the area adjacent to the dredged area. Effects of contaminated supernatant on invertebrate fauna in the undredged areas adjacent to the dredge and downstream of the basin outflow pipe have yet to be conclusively determined. Further work will be necessary to get a more definitive picture.

Due to the late start of the active dredging operations, most of the actual dredging goals were not fully met. Primarily, we were not able to dredge a sufficient amount of material to conclusively determine the feasibility of dredging or obtain an indication of costs involved. We were also not able to conduct any of the post-dredging treatment studies that are important in proving the feasibility of using the retention basin as a basis for large-scale natural attenuation of contaminated sediments through land farming. These shortcomings can be addressed with resumption of dredging activities next field season. Attenuation studies will be conducted with Marianne Walsh as an extension of her previous natural attenuation work.

One issue not addressed in the 1994 field scope of work is the eventual disposition of the treated sediments. To make the dredging option more economical, the retention basin will need to be reused. That will require the excavation of the dried and consolidated sediments. Placing these treated sediments back in the Flats has been determined to be impractical from a regulatory point of view, although technologically it is feasible. The option currently being considered is spreading the treated spoils on the EOD pad adjacent to the basin, using them as a capping or sub-capping material. Characteristics of the pad and the pad capped by a thin layer of spoils have been determined from 1994 field work and can be used by the RPMs in determining the acceptability of this option.

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APPENDIX A: DREDGING SURVEY INFORMATION PACKAGE

The following are excerpts from the ERF information package that was assembled and distributed to several dredge manufacturers visited in January and February of 1994. The objective of this information was to give the manufacturers sufficient information to determine the feasibility of dredging in the Flats.

Information Package for Dredge Manufacturers

LOCATION: Eagle River Flats, Fort Richardson, Alaska.
AREA TO BE DREDGED: Ponds in Area C. Area C is approximately 45 acres total, consisting of a large 25-acre pond connected to several smaller ponds.
WATER DEPTH: Varies between < 1″ to 15″.
TIDES: Pond areas will flood only during extreme high tides occurring in combination with high river discharge.
DREDGING DEPTH: 24″ to 30″ maximum.
MAXIMUM DISTANCE FROM DREDGE TO SPOIL AREA: ≈ 2500′ maximum.
PUMPING ELEVATION: Approximately 8′ to 10′ maximum.
MATERIAL TO BE DREDGED: Silt or clay, mostly silt.
RECORDED ORDNANCE FIRED INTO ERF: ≈ 100,000 (× 10% = 10K UXOs).

ORDNANCE SPECIFICATIONS

Mortar Rounds*		
• **60 mm**	Weight:	≈ 4 pounds
	Diameter:	2 3/8″ø
	Length:	9.6–14.7″ (Total)
		2.75–5″ (Fin assembly)
• **81 mm**	Weight:	≈ 10 pounds
	Diameter:	3 3/16″ø
	Length:	13–24″ (Total)
		3.5–7.8″ (Fin assembly)
• **107 mm**	Weight:	≈ 26 pounds
	Diameter:	4.2″ ø
	Length:	20–26″ (Total)
		(No fin assembly)
Howitzer Rounds*		
• **105 mm**	Weight:	≈ 40 pounds
	Diameter:	4.13″ ø
	Length:	16.9″ (Total)

Unexploded ordnance

It has been estimated that 100,000 artillery rounds have been fired into ERF. The standard stated dud rate for artillery rounds is on the order of 10% (4%–20%). This gives us a maximum of 10,000 rounds of unexploded ordnance (UXOs). There is no way of telling how many of these still exist and are dangerous. If one assumes that most UXOs were fired into heavily utilized areas or ranges, then a significant portion of these duds may have been detonated or destroyed by subsequent incoming rounds. Very few UXOs have been observed at or near the surface of the Flats, although this is not necessarily an indication that there are very few UXOs. Mortar

*From FM 9-13, Ammunition Handbook (U.S. Army 1981). All rounds high explosive (HE).

tail fin assemblies, on the other hand, are much more ubiquitous, as there is an assembly somewhere on the Flats for every 60- and 81-mm round lobbed.

Our current understanding is that UXOs are to be handled only by the Explosive Ordnance Disposal (EOD) team at the base. There are two options for dredging around the UXOs: suction (non-contact) dredging of silt around the UXO, allowing it to fall away from or be bypassed by the dredge, or dredging with a mechanical auger as a dredgehead, which will chew up the smaller and more oxidized UXOs, hopefully without detonating the rounds. More intact rounds may be driven into the mud or be ridden over. An explosion cannot be ruled out. Problems may arise with the compromising of a white phosphorus (WP) round. Pump cavitation or discharge exposure may spontaneously ignite the WP.

APPENDIX B: RETENTION BASIN MODEL

The following model of the retention basin to be constructed on the EOD pad was developed by M.R. Walsh and E.J. Chamberlain of CRREL. The model assumes input from the dredge at 382 m^3/hour, with a 4:1 water-to-saturated-soil ratio. The following are the parameters on which this model is based:

- Hydraulic conductivity of sludge = 15×10^{-4} mm/sec.
- Hydraulic conductivity of the 152-mm compacted liner = 58×10^{-6} mm/sec (Corrected for 15° C).
- No compaction of sludge layer (and associated decrease in hydraulic conductivity) assumed.
- Three-hour settling time between pumping and decanting over weir.
- Remove 7.6 cm/hour from height of weir for each of first four hours (Hours 12–15). Fifth hour (Hour 16) is a decanting drain.
- Ref.: Annual precipitation in Anchorage area ≈ 38.9 cm (15.3")/yr.
- 7.3-m- (24') long weir.
- $k = 1.5 \times 10^{-4}$ cm/sec.

The following are conditions set on the model:

Site size: 9680 m^2 (≈ 2.5 acres)
Water in per eight-hour day @ 382 m^3/hour: 2850 m^3
Saturated sludge pumped per day: 610 m^3
Sludge depth per day, 0.8-ha site: 0.075 m (75.4 mm)
Water depth per day, 0.8-ha site: 302.4 mm
Water depth per hour, 0.8-ha site: 37.9 mm

Equations used throughout this model and given following the model.

Table B1. Retention basin drainage and infiltration model.

Based on 20% solids and 5 ppt salinity, lined basin.

Day	Hour	*Drain time (dt) (hours)*	*Excess water quantity: Q in (m^3)*	*Additional thickness of sludge (mm)*	*Thickness of sludge (mm)*	*Height of water column (mm)*	*Q water pad (m^3)*	*Q water weir (m^3)*	*Drainage thru pad (m^3)*	*Decant over weir (m^3)*	*Error (m^3)*
1	1	15.5	306	9.4	9.40	37.6	2.0	0			
	2	14.5	306	9.4	18.80	75.2	2.6	0			
	3	13.5	306	9.4	28.20	112.7	3.2	0			
	4	12.5	306	9.4	37.60	150.1	3.8	0			
	5	11.5	306	9.4	47.00	187.5	4.4	0			
	6	10.5	306	9.4	56.40	224.7	5.0	0			
	7	9.5	306	9.4	65.80	262.0	5.5	0			
	8	8.5	306	9.4	75.20	299.1	6.1	0			
	9	7.5	0	0.0	75.20	298.3	6.7	0			
	10	6.5	0	0.0	75.20	297.5	6.7	0			
	11	5.5	0	0.0	75.20	296.6	6.7	0			
	12	4.5	0	0.0	75.20	242.7	6.7	429			
	13	3.5	0	0.0	75.20	170.0	6.0	582			
	14	2.5	0	0.0	75.20	113.4	5.1	453			
	15	1.5	0	0.0	75.20	43.2	4.3	563			
	16	0.5	0	0.0	75.20	16.2	3.4	216	78	2243	–4.3
2	1	15.5	306	9.4	84.60	37.4	3.1	0			
	2	14.5	306	9.4	94.00	74.9	3.5	0			
	3	13.5	306	9.4	103.40	112.3	4.1	0			
	4	12.5	306	9.4	112.80	149.6	4.6	0			
	5	11.5	306	9.4	122.20	186.9	5.2	0			
	6	10.5	306	9.4	131.60	224.1	5.8	0			
	7	9.5	306	9.4	141.00	261.2	6.4	0			
	8	8.5	306	9.4	150.40	298.2	6.9	0			
	9	7.5	0	0.0	150.40	297.3	7.5	0			
	10	6.5	0	0.0	150.40	296.4	7.5	0			
	11	5.5	0	0.0	150.40	295.5	7.5	0			
	12	4.5	0	0.0	150.40	241.5	7.5	429			
	13	3.5	0	0.0	150.40	169.1	6.8	578			
	14	2.5	0	0.0	150.40	112.5	5.9	452			
	15	1.5	0	0.0	150.40	42.7	5.2	560			
	16	0.5	0	0.0	150.40	15.9	4.3	212	92	2232	–4.3

Table B1 *(cont'd).*

Day	Hour	Drain time (dt) (hours)	Excess water quantity: Q in (m^3)	Additional thickness of sludge (mm)	Thickness of sludge (mm)	Height of water column (mm)	Q water pad (m^3)	Q water weir (m^3)	Drainage thru pad (m^3)	Decant over weir (m^3)	Error (m^3)
3	1	15.5	306	9.4	159.80	37.3	4.0	0			
	2	14.5	306	9.4	169.20	74.7	4.3	0			
	3	13.5	306	9.4	178.60	112.0	4.9	0			
	4	12.5	306	9.4	188.00	149.2	5.5	0			
	5	11.5	306	9.4	197.40	186.4	6.0	0			
	6	10.5	306	9.4	206.80	223.5	6.6	0			
	7	9.5	306	9.4	216.20	260.5	7.1	0			
	8	8.5	306	9.4	225.60	297.4	7.7	0			
	9	7.5	0	0.0	225.60	296.4	8.2	0			
	10	6.5	0	0.0	225.60	295.4	8.2	0			
	11	5.5	0	0.0	225.60	294.4	8.2	0			
	12	4.5	0	0.0	225.60	240.3	8.2	429			
	13	3.5	0	0.0	225.60	167.9	7.5	578			
	14	2.5	0	0.0	225.60	111.2	6.7	452			
	15	1.5	0	0.0	225.60	41.3	6.0	559			
	16	0.5	0	0.0	225.60	15.5	5.1	204	104	2222	–4.3
4	1	15.5	306	9.4	235.00	37.2	4.8	0			
	2	14.5	306	9.4	244.40	74.5	5.2	0			
	3	13.5	306	9.4	253.80	111.7	5.7	0			
	4	12.5	306	9.4	263.20	148.8	6.3	0			
	5	11.5	306	9.4	272.60	185.9	6.8	0			
	6	10.5	306	9.4	282.00	222.9	7.4	0			
	7	9.5	306	9.4	291.40	259.8	7.9	0			
	8	8.5	306	9.4	300.80	296.6	8.4	0			
	9	7.5	0	0.0	300.80	295.5	9.0	0			
	10	6.5	0	0.0	300.80	294.4	8.9	0			
	11	5.5	0	0.0	300.80	293.3	8.9	0			
	12	4.5	0	0.0	300.80	239.2	8.9	429			
	13	3.5	0	0.0	300.80	166.8	8.3	577			
	14	2.5	0	0.0	300.80	110.0	7.4	452			
	15	1.5	0	0.0	300.80	40.1	6.7	559			
	16	0.5	0	0.0	300.80	15.1	5.9	196	117	2214	–4.3

Table B1. Retention basin drainage and infiltration model *(cont'd)*.

Day	Hour	Drain time (dt) (hours)	Excess water quantity: Q in (m^3)	Additional thickness of sludge (mm)	Thickness of sludge (mm)	Height of water column (mm)	Q water pad (m^3)	Q water weir (m^3)	Drainage thru pad (m^3)	Decant over weir (m^3)	Error (m^3)
5	1	15.5	306	9.4	310.20	37.1	5.6	0			
	2	14.5	306	9.4	319.60	74.3	6.0	0			
	3	13.5	306	9.4	329.00	111.4	6.5	0			
	4	12.5	306	9.4	338.40	148.4	7.0	0			
	5	11.5	306	9.4	347.80	185.4	7.6	0			
	6	10.5	306	9.4	357.20	222.3	8.1	0			
	7	9.5	306	9.4	366.60	259.1	8.6	0			
	8	8.5	306	9.4	376.00	295.9	9.1	0			
	9	7.5	0	0.0	376.00	294.7	9.7	0			
	10	6.5	0	0.0	376.00	293.5	9.6	0			
	11	5.5	0	0.0	376.00	292.3	9.6	0			
	12	4.5	0	0.0	376.00	238.1	9.6	429			
	13	3.5	0	0.0	376.00	165.7	9.0	576			
	14	2.5	0	0.0	376.00	108.8	8.1	452			
	15	1.5	0	0.0	376.00	38.9	7.5	558			
	16	0.5	0	0.0	376.00	14.7	6.6	189	128	2205	–4.3
6	1	15.5	306	9.4	385.40	37.0	6.4	0			
	2	14.5	306	9.4	394.80	74.1	6.7	0			
	3	13.5	306	9.4	404.20	111.1	7.2	0			
	4	12.5	306	9.4	413.60	148.1	7.8	0			
	5	11.5	306	9.4	423.00	184.9	8.3	0			
	6	10.5	306	9.4	432.40	221.7	8.8	0			
	7	9.5	306	9.4	441.80	258.5	9.3	0			
	8	8.5	306	9.4	451.20	295.2	9.8	0			
	9	7.5	0	0.0	451.20	293.9	10.3	0			
	10	6.5	0	0.0	451.20	292.6	10.3	0			
	11	5.5	0	0.0	451.20	291.4	10.3	0			
	12	4.5	0	0.0	451.20	237.0	10.3	429			
	13	3.5	0	0.0	451.20	164.6	9.6	576			
	14	2.5	0	0.0	451.20	107.7	8.8	452			
	15	1.5	0	0.0	451.20	37.7	8.2	558			
	16	0.5	0	0.0	451.20	14.3	7.4	182	139	2197	–4.3

Table B1 *(cont'd).*

Day	Hour	Drain time (dt) (hours)	Excess water quantity: Q in (m^3)	Additional thickness of sludge (mm)	Thickness of sludge (mm)	Height of water column (mm)	Q water pad (m^3)	Q water weir (m^3)	Drainage thru pad (m^3)	Decant over weir (m^3)	Error (m^3)
7	1	15.5	306	9.4	460.60	36.9	7.1	0			
	2	14.5	306	9.4	470.00	73.9	7.4	0			
	3	13.5	306	9.4	479.40	110.8	8.0	0			
	4	12.5	306	9.4	488.80	147.7	8.5	0			
	5	11.5	306	9.4	498.20	184.5	9.0	0			
	6	10.5	306	9.4	507.60	221.2	9.5	0			
	7	9.5	306	9.4	517.00	257.9	10.0	0			
	8	8.5	306	9.4	526.40	294.5	10.5	0			
	9	7.5	0	0.0	526.40	293.1	11.0	0			
	10	6.5	0	0.0	526.40	291.8	10.9	0			
	11	5.5	0	0.0	526.40	290.4	10.9	0			
	12	4.5	0	0.0	526.40	236.0	10.9	429			
	13	3.5	0	0.0	526.40	163.6	10.3	575			
	14	2.5	0	0.0	526.40	106.6	9.5	452			
	15	1.5	0	0.0	526.40	36.6	8.8	557			
	16	0.5	0	0.0	526.40	14.0	8.1	175	150	2189	–4.3
8	1	15.5	306	9.4	535.80	36.9	7.8	0			
	2	14.5	306	9.4	545.20	73.8	8.1	0			
	3	13.5	306	9.4	554.60	110.6	8.6	0			
	4	12.5	306	9.4	564.00	147.4	9.1	0			
	5	11.5	306	9.4	573.40	184.1	9.6	0			
	6	10.5	306	9.4	582.80	220.7	10.1	0			
	7	9.5	306	9.4	592.20	257.3	10.6	0			
	8	8.5	306	9.4	601.60	293.8	11.1	0			
	9	7.5	0	0.0	601.60	292.4	11.6	0			
	10	6.5	0	0.0	601.60	291.0	11.6	0			
	11	5.5	0	0.0	601.60	289.5	11.5	0			
	12	4.5	0	0.0	601.60	235.1	11.5	429			
	13	3.5	0	0.0	601.60	162.7	10.9	575			
	14	2.5	0	0.0	601.60	105.6	10.1	452			
	15	1.5	0	0.0	601.60	35.6	9.5	557			
	16	0.5	0	0.0	601.60	13.6	8.7	169	161	2182	–4.3

Flow Summary

System Characteristic	Q Pad	Q Weir	Error
Cumulative totals (Cubic meters)	969	17,684	–34
Error (%)			0.18
Equivalence in mm of water/year	120	2,185	–4

Notes: Hydraulic conductivity of sludge = $15 \bullet 10^{-4}$ mm/sec.

Hydraulic conductivity of the 152-mm compacted liner = $58 \bullet 10^{-6}$ mm/sec (corrected for 15° C).

No compaction of sludge layer (and associated decrease in hydraulic conductivity) assumed.

Three-hour settling time between pumping and decanting over weir.

Remove 76.2 mm/hr from weir for first four hours (Hours 12–15). Fifth hour (Hour 16) is a decanting drain.

Ref: Annual precipitation in Anchorage area ≈ 390 mm/yr.

7.3-m-long weir.

Key to Calculations

Equations used (See Day 8, Hour 3: Row 145).

Note: Column H corresponds to Q water (Pad), F to Thickness of Sludge, and G to Height of Water Column

G144 + 37.8 – (H145 • 1000/8090) (Height of Water Column)

$$8090 \bullet 3600 \bullet [(68 \bullet 10^{-6})/1000] \bullet (152 + F144 + G144)/\{152 + [F144 \bullet (68 \bullet 10^{-6})/(15 \bullet 10^{-4})]\}$$

(Q water: Pad)

Equations used (See Day 8, Hour 13: Row 133).

Note: Column H corresponds to Q water (Pad), F to Thickness of Sludge, and G to Height of Water Column

G149 – (H150 + I150) • 1000/8090 (Height of Water Column)

$$8090 \bullet 3600 \bullet [(68 \bullet 10^{-6})/1000] \bullet (152 + F149 + G149)/\{152 + [F149 \bullet (68 \bullet 10^{-6})/(15 \bullet 10^{-4})]\}$$

(Q water: Pad)

$$8.09 \bullet \left[152 - (G148 - G149) - 12 \bullet 25.4 \bullet \{1/[1.63 + 1/SQRT(\{6 - [(G148 - G149)/25.4]\}/12)]\}^2\right]$$

(Q water: Weir)

8090	2-acre site size in square meters
2850	Water in per 8-hr day @382 m^3/hr.
610	Sludge in per day (m^3)
0.075	Sludge depth (m) per day, 2-acre site.
75.4	Sludge depth (mm) per day, 2-acre site.
302.4	Water depth (mm) per day, 2-acre site.
37.8	Water depth (mm) per hour, 2-acre site.

k = 15E(–4) mm/sec

APPENDIX C: SPOILS SAMPLE COLLECTION, STORAGE, AND SHIPMENT SOP

Sample collection

Collection point: Spoils line, approximately 12 m upstream from crest of retention pond berm.

Sampling access: 13-mm pitless adapter on side of spoils line. Ball valve shutoff.

Sample strategy: Composite sample method. Samples are taken at 15-minute intervals by directing a stream of spoils from the spoils line through the pitless adapter, valve and 1 m of Tygon tubing into a 19-L PE bucket. After four samples have been taken, the volume is stirred and a 500-ml composite sample taken using a PE ladle. The sample container is a clear, wide-mouth 500-ml glass sample jar, level 2A clean (Eagle-Pitcher P/N 232-16C). Time, date and approximate dredge location are noted. The bucket is then emptied and rinsed twice with distilled water for reuse.

Sample storage

Temperature: Temperature is not to exceed 15° C.

Location: Samples are not to be stored in direct sunlight. Whenever possible, they will be stored in a cooler.

Documentation: All samples are to be labeled. Documentation will reside with samples whenever practicable. A duplicate set of documentation will be retained by the P.I. or sampler.

Sample shipment

Samples are to be shipped overnight or second-day air, whichever method is most practicable. Samples are to be shipped to ensure temperature does not exceed 15° C. Adequate packing to ensure sample integrity will be used. Containers are to be sealed with a chain of custody document attached.

APPENDIX D: DECANTED SUPERNATANT SAMPLE COLLECTION, STORAGE, AND SHIPMENT SOP

Sample collection

Collection point: Drop inlet structure outlet pipe egress point.

Sampling access: Open area accessible at all times.

Sample strategy: Grab sample taken once or twice a day during decanting process. Samples taken by placing the mouth of a 1-L amber glass sample bottle, level 2A clean (Eagle-Pitcher P/N 223-32A), in the path of the outflow from the outlet pipe. Time and date are noted.

Sample storage

Temperature: Temperature is not to exceed 15° C.

Location: Samples are not to be stored in direct sunlight. Whenever possible, they will be stored in a cooler.

Documentation: All samples are to be labeled. Documentation will reside with samples whenever practicable. A duplicate set of documentation will be retained by the P.I. or sampler.

Sample shipment

Samples are to be shipped overnight or second-day air, whichever method is most practicable. Samples are to be shipped to ensure temperature does not exceed 15° C. Adequate packing to ensure sample integrity will be used. Containers are to be sealed with a chain of custody document attached.

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Remediation of sediments in permanently ponded areas at Eagle River Flats, a salt marsh contaminated with white phosphorus (WP), may require dredging. Because the Flats were used as a firing range impact area for over 40 years by the U.S. military, there is much unexploded ordnance, which will require that any dredging equipment be remotely controlled. To treat the sediment pumped from dredged areas, a spoils retention basin was designed, constructed, and tested. This basin contains several innovations, including a natural peaty-silt liner and a geofabric barrier to inhibit reintroduction of WP into the environment, and is designed for the natural remediation of the WP. The dredging system was deployed in October of 1994, with sampling indicating that WP-contaminated areas were removed from the dredged area. An early snowfall curtailed operations shortly after initiation.

14. SUBJECT TERMS
Dredging; Eagle River Flats; Geofabrics; Natural remediation; Remote control; Spoils retention basin; White phosphorus (WP or P_4)

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